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"IGOR SIKORSKY KYIV POLYTECHNICAL INSTITUTE"

Institute of Energy Saving and Energy Management

Power Supply Department

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Head of the Department
___________ Volodymyr POPOV
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Master's thesis

under the specialty: 141 Electrical Energetics, Electrical Engineering and Electromechanics
Educational and Professional Program: Engineering of systems for providing consumers with electric energy

on the topic: "Using the possibilities of combyned operation of TPP and SPP in the system of guaranteed electricity supply to consumers"

Completed by: Master student (2d year), group OE-91mp

Lavrynovych Pavlo ___________
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Reviewer Professor Konrad Świrski ___________
(Scientific degree, academic title, full name) (Signature)

I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.
Student ______________
(Signature)

Kyiv, 2020

National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”
Institute of Energy Saving and Energy Management
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Level of higher education: second (Master’s), educational and professional program

Specialty: 141 Electrical Energetics, Electrical Engineering and Electromechanics
Name of the program: Engineering of systems for providing consumers with electric energy

“APPROVED”
Head of the Department
__________ Volodymyr POPOV
“___” _____________ 2020

TASK
on the Master’s thesis research to student
Pavlo LAVRYNOVYCH

1. Topic of the Master’s thesis: “Using the possibilities of combyned operation of TPP and SPP in the system of guaranteed electricity supply to consumers”
Research advisor: Ph.D., Ass. Prof. Zamulko Anatoly_______________________
approved by the university order dated on «03» _November_ 2020 № 3199-c

2. Deadline for the Master’s thesis submission by student: _«13» _December_ 2020

3. Object of research: Regulation process of SPP and TPP operation______________

4. Input data: daily schedules of station generation, modes of operation of stations, general statistics of change of work of SPP concerning the period of the year, methodical instructions, the list of tasks from the scientific adviser
____

5. List of the tasks that have to be performed: - to analyze the main structural features of TPP operation; ____
- to analyze the main structural features of the SPP________________________
- to form the parameters of the main generating equipment of the system__________
- perform calculations confirming the possibility of application_________________
integrated system relative to the connection point of renewable energy installations.

6. List of the graphical (illustrative) material: presentation - visual materials on the study results, calculation algorithms and tables with the results obtained.
____

7. Indicative list of publications: ____

1. Features of guaranteed power supply schemes for networks with renewable energy sources formation____

2. Investment economic calculation (NPV) – large solar power plant (Ukrainian market) ____

8. Consultants for different sections of the Master's thesis: ________________

9. Date, when the task was issued: _____________________________________

Calendar plan

№ з/п	Name of the stage of the Master's thesis implementation	Terms of implementation	Notes
1.	Identification the purpose of research, object and subject of research	11.05.2020-18.05.2020	
2.	Identification the preliminary structure of the Master's thesis	19.05.2020-25.05.2019	
3.	Literature review and work on the first section of the Master's thesis	25.05.2020-21.06.2020	
4.	Define methodology and methods of research features of TPP and SES operation	21.06.2020-15.07.2020	
5.	Formation of parameters of photovoltaic system	15.07.2020-10.09.2020	
6.	Development of methods and means of project calculation	10.09.2020-14.11.2020	
7.	Formatting the text of the Master's thesis	14.11.2020-11.12.2020	
8.	Preparing the Abstract and PowerPoint Presentation of the Master's thesis; receiving an official protocol of plagiarism detection results and peer review	11.12.2020-9.12.2020	
9.	Preliminary Master's thesis defense	17.12.2020	
10.	Master's thesis defense	18.12.2020	

Student __________ Pavlo LAVRYNOVYCH

Research Advisor __________ Anatoly ZAMULKO

ABSTRACT

Structure and scope of work. The Master's thesis on the topic "Using the possibilities of combyned operation of TPP and SPP in the system of guaranteed electricity supply to consumers" consists of an introduction, 4 sections, conclusions and list of references. The total volume of work is 109 pages, including 21 figures, 22 tables and 103 bibliographic references, 6 annexes on the 18 pages.

Relevance of research. Increasing the frequency of power outages and deteriorating equipment encourages the use of additional energy sources. Based on the experience of developed countries, we can conclude that the solution may be a renewable energy source.

RES are developing dynamically, including due to their efficiency and environmental friendliness. Solar energy is one of the most efficient branches of alternative (renewable) energy.

Solar energy is exclusively ecological, it does not affect the environment. Its development is stimulated as purely economic factors. This includes regular increases in prices for traditional energy sources, reducing the cost of equipment for stations running on alternative sources. The cost of SPP itself is much lower compared to other alternative methods of electricity generation, such as wind farms. And the main thing is support in the form of a green tariff from the government.

However, SPP also has its drawbacks, the main ones being the complexity of energy storage, energy regulation and forecasting and the large area of application.

To address such issues, a combination of SPP with TPP is proposed.

In the modern power system of Ukraine, a large share of thermal energy is used partially or completely decommissioned, as well as stored. This problem is due to insufficient funding for equipment modernization, so the capacity of TPPs in these realities is much less than was found in the design of lines and transformer substations that connect generation to the distribution unit. Also due to reduced generation, TPP ash dumps are empty and can be used to install SPP.

Relationship of work with scientific programs, plans, themes. The researches performed in the work correspond to the direction "Auction for

distribution of support quota”, which refers to the amendment to the Law of Ukraine № 810-IX of 21.07.2020 “On alternative energy sources”. These amendments also include "Stimulating the production of electricity from alternative energy sources". The law defines the legal, economic, environmental and organizational principles of the use of alternative energy sources and promotes the expansion of their use in the fuel and energy sector. Also, the research is in line with the goal "Goal 7. Ensuring access to affordable, reliable, sustainable and modern energy sources for all", which refers to the global process of sustainable development.

Purpose and tasks of the research. Ensuring reliable electricity supply to consumers, reducing the use of fossil fuels for electricity generation and analysis of the possibility of creating a system that will regulate the combined system of TPPs and SPP

Object of research. Regulation process of SPP and TPP operation/

Subject of research. Methods and means of comprehensive assessment of the functioning of the TPP system and the possibility of implementing SPP.

Practical value of the results. To solve this problem, the general methodology of scientific research, calculation of component systems, as well as the decision on the possibility of combining the two systems were used.

The information base of the study consisted of laws and regulations of public administration in the field of energy, laws of Ukraine, official statistics, as well as scientific works of domestic and foreign scientists. The dissertation used software such as MS Excel, HelioScope, AutoCad.

Scientific novelty of the obtained results. Scientific novelty is justified by the fact that this concept of combining the two systems allows to mutually compensate for each other's shortcomings. Unlike previous studies, the system takes into account the vulnerabilities of the installation and operation of a solar station and reduces the negative impact of greenhouse gas emissions from fossil fuel combustion.

Also, the system is equipped with the ability to accumulate electrical energy in rechargeable batteries, which provides an additional reserve for regulating the operation of SPP.

Approbation of the Master’s thesis and publications. The results of the research were made public at two scientific and technical conferences and included in the collections of works:

1. Lavrynovych Pavlo. Features of formation of guaranteed power supply schemes for networks with renewable energy sources. // XII scientific and technical conference of the institute of energy saving and energy management “Energy. Ecology. Man” - May 7, 2020.

2. Lavrynovych Pavlo. Investment economic calculation (NPV) – large solar power plant (Ukrainian market). // III scientific and technical conference of IEE masters - November 26, 2020.

Key words: *warranty power supply systems, solar power plant, thermal power plant, renewable energy sources, backup power, green tariff.*

CONTENTS

LIST OF ABBREVIATIONS

PSS – power supply system.

SPP – solar power plant.

USSR – Union of Soviet Socialist Republics.

RES – renewable energy sources.

LLC – Limited Liability Company.

ICU – Investment Capital Ukraine.

HPP – hydro power plant.

EBRD – European Bank for Reconstruction and Development.

BSTDB – Black Sea Trade and Development Bank.

ATS – automatic transfer switch.

NPP – nuclear power plant.

TPP – thermal power plant.

CPP – condensing power plants.

CHP – combined heat and power station.

CIS – Commonwealth of Independent States.

RTO – Rules of technical operation.

VAR – variable.

SVC – static VAR compensator.

STATCOM – static synchronous compensators.

SCADA – supervisory control and data acquisition.

PVPS – Photovoltaic Power System.

IRR – internal rate of return.

NPV – net present value.

WPP – Wind Power Plant.

NCSREU – National Commission for State Regulation of Energy and Public Utilities.

PPA – Power Purchase Agreement.

MPPT – maximum power point tracker.

DC – direct current.

AC – alternating current.

DOD – depth of the discharge.

PTSUN – Packaged Transformer Substation for Urban Electrical Networks.

HVS – high voltage switchgear.

HVD – high voltage device.

MPTSUN – Modernized Packaged Transformer Substation for Urban Electrical Networks.

CAPEX – CAPital EXpenditure.

OPEX – OPerating EXpenditure.

IPS – Integrated Power System.

SWOT – Strengths-Weaknesses-Opportunities-Threats.

INTRODUCTION

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Solar energy is exclusively ecological, it does not affect the environment. Its development is stimulated as purely economic factors. This includes regular increases in prices for traditional energy sources, reducing the cost of equipment for stations running on alternative sources. The cost of SPP itself is much lower compared to other alternative methods of electricity generation, such as wind farms. And the main thing is support in the form of a green tariff from the government.

However, SPP also has its drawbacks, the main ones being the complexity of energy storage, energy regulation and forecasting and the large area of application.

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In addition to the relationship, there is an option to add an array of batteries to the system. This improves the quality and efficiency of employees.

Relationship of work with scientific programs, plans, themes. The researches performed in the work correspond to the direction “Auction for distribution of support quota”, which refers to the amendment to the Law of Ukraine № 810-IX of 21.07.2020 “On alternative energy sources”. These amendments also include "Stimulating the production of electricity from alternative energy sources".

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Also, the system is equipped with the ability to accumulate electrical energy in rechargeable batteries, which provides an additional reserve for regulating the operation of SPP.

1 ANALYSIS OF EXISTING WARRANTY SYSTEMS OF POWER SUPPLY

1.1 Warranty systems of power supply

Increasing the frequency of disconnections from the grid encourages consumers to take a number of measures to reduce the risk of overload and to increase the reliability of energy supply. The solution of such issues is the installation and use of backup power sources.

Reliability is the property of a power system to perform tasks for proper functioning. When assessing the reliability of power supply systems (PSS), its ability to supply to specific consumers is considered. Denial of electricity to at least one consumer connected to the network causes the consequences of non-compliance with the entire system of electricity supply to consumers [1].

"Microenergy" - is currently one of the leading ways of redundancy to increase the reliability of energy supply.

Currently, there is a tendency to increase the production of electricity produced through the use of "microenergy" by independent producers.

Due to the inadequate state of the energy system, many countries are using the prospects of using alternative sources of electricity. This trend is pronounced in countries with economic transition [1].

Some types of alternative energy have now gained considerable popularity, namely:

- wind energy;
- solar energy;
- hydrogen fuel cells;
- means and devices of energy generation that run on traditional fuel.

The basis of the hydrogen fuel cells technology is special equipment - a membrane by which the electron is separated from the nucleus of the hydrogen atom, resulting in an electric current. This alternative is only gaining popularity, as it does not affect the ecological situation of the environment. The only wastes of this technology are water and heat [1].

These sources can act as an additional source for consumers of the first category and ensure the production of the required amount of electricity.

Solar power plant (SPP) is selected as such additional source for this object of study, it will be able to fully meet the needs of the consumer. The selection of SPP elements and further calculations are carried out in Section 3 of the diploma project.

For electric receivers of a special group and each of the three categories is normalized the number of independent mutually redundant power supplies and the duration of the power outage (Table 1.1) [1].

Table 1.1 – Number of independent mutually redundant power supplies and duration of power outage.

Electrical receivers categories	Minimum number of independent power supplies	Maximum duration of power outage
Special group	3	Automatic time power recovery
I	2	Automatic time power recovery
II	2	Manual time power recovery
III	1	1 day

To objectively assess the reliable operation of SPP, its ability to work or not to work in relation to specific consumers is considered.

During solving the problems of reliability analysis and managing the development and operation of systems, it is necessary to count the number of failures, which will lead to further power outages and undersupply of electricity to consumers. The main factors are: lack of electricity and power in the system, which in turn occurs due to accidents at source, emergency shutdowns of consumers in order to avoid the development of accidents in case of short circuits on the lines, power supply interruption, as well as during scheduled repairs in networks that are not equipped with redundancy, periodic outages due to the action of relay protection.

The most dynamically developing source of electricity, including due to its efficiency and environmental friendliness, is solar energy - one of the branches of alternative (renewable) energy. It is based on the conversion of energy emitted by the Sun into other types of energy, such as electrical or thermal [2].

Solar energy is exclusively ecological, it has no impact on the environment. Its development is stimulated as purely economic factors (these include the regular increase in prices for traditional energy sources (coal, oil, peat, gas), reducing the cost of equipment for stations operating on alternative energy sources with constant modernization, which in general allows to influence the cost of electricity produced. The cost of SPP itself, compared to other alternative methods of electricity generation, such as wind farms, is much lower), and support in the form of a green tariff from the government [2].

In recent years, the growth of the capacity of solar power plants that go into operation, in recent years, occupies about half of all alternative energy. In just fifty years, the share of solar energy in the world has exceeded 5%. Improving the technology of manufacturing photovoltaic modules has led to a significant reduction in the cost of solar electricity - in more than 30 countries (Germany, Chile, Australia, Mexico) it has become cheaper than obtained from traditional (oil, gas, coal) sources. Over the past 10 years, investments in solar energy have amounted to about $ 300 billion. The most illustrative example of the success of the use of solar technology - the island of Tau (American Samoa), which previously depended entirely on the supply of diesel fuel, after the installation of modern SPP became completely independent.

Climatic conditions and geographical location of Ukraine contribute to the development of solar energy and the construction of such PSS. As an example, Germany, a country that is geographically located much north of Ukraine, at the same time occupies a leading position in the world in the generation of solar electricity [2].

Compared to traditional sources, the efficiency of "microenergy" is much higher. The most important thing is that autonomous energy sources will allow the consumer, remote from the power system, to ensure the desired level of supply and reliability of electricity, especially in a period when the reliability of supply has decreased significantly.

Energy sources that belong to the "microenergy" have a much higher efficiency than the most efficient traditional.

1.2 The urgency of the issue of providing warranty power supply systems

The main global trend is the transition to the principles of sustainable development.

All countries are required to develop concepts for their sustainable development. Ukraine already has such a concept. The Energy Strategy of Ukraine, of course, also implements the principles of sustainable development.

The implementation of the sustainable development principles requires a rethinking of energy policy, especially electricity. At the heart of the new policy is, on the one hand, a clear focus on energy production to fully meet human needs, and on the other hand - a focus on changing human consumer psychology in order to reduce these needs.

Another basic principle of this policy is to limit the consumption of fuel resources not so much because of their lack, but because of the inability of the biosphere to withstand the load of large-scale use of resources. Due to these principles, electric power itself must undergo qualitative changes [3].

Therefore, it is necessary to pose and solve a new problem - to focus energy on the maximum satisfaction of needs of the concrete person, rendering to it of energy services - various and convenient. As a result, decentralized energy in various forms will be greatly developed [1].

People all over the world have a desire to live in abundance and comfort, and this requires decentralized energy life support systems. There are many electrical appliances are in every apartment today, and in the future, there will be even more. That is, energy has already been developed to increase the comfort of our lives [1].

Ukraine got the energy sector from the USSR, which is represented by high-power power units, most of which have low maneuverability (designed to work in basic mode), and are not able to provide the peak part of the load schedule. Therefore, the construction of autonomous low-power energy sources (from hundreds of watts to MW) will be able to solve this problem [1].

The unified power system of Ukraine, created from a part of the power system of the USSR, is outdated. Given the rapid development of technology and, consequently, the increase in the general needs of the population, the energy system needs to be modernized. One option to address this issue is to install decentralized stations that will help provide sufficient electricity in specific areas of the system and for specific consumers. Such decentralized stations are a direct way to address the issue of guaranteed electricity supply to consumers whose geographical location is difficult to access.

Also, due to the development of industry and the increase of its power units, there is a need to develop a power supply system.

As autonomous sources of energy consider the means of "microenergy", which run on solar energy, namely: solar power plants.

The following types of solar power plants are popular in Ukraine:

- solar power plants for industrial use;
- medium solar power plants;
- home solar power plants.

Industrial solar power plants have become popular due to significant cost savings and the ability to connect in difficult locations for transmission companies.

1.3 Statistics of development of industrial SPP in Ukraine as of 2019-2020

The rapid rise in the construction of solar industrial facilities in 2019 is a significant phenomenon. During this time, the "green tariff" was officially received by 493 industrial SPP with a total installed capacity of 3537,382 MW, which is 5.5 times higher than in 2018 [4].

This year, the world community has faced a number of economic difficulties that have not escaped Ukraine, in addition to internal specific problems in the energy sector. However, these problems are surprisingly combined with great success SPP in the field of RES. The construction of renewable energy facilities is a rather inertial process, and even if you want to, it takes time to stop it.

2019 — rapid rise. Solar power plants are long-term projects that cannot be stopped quickly for a number of known reasons. Therefore, despite the fact that the energy sector of our country in general and SPP segments in particular are now dealing with serious management problems, performance indicators, in this case solar energy, in 2019 show a bright positive trend [4].

Thus, as of 01.01.2020, the total installed capacity of industrial SPP in our country has reached 4924.610 MW. At the same time, for 12 months of 2019, the “green” tariff was officially received by stations with a total capacity of 3537.382 MW, which is 5.48 times higher than the same indicator in 2018 (645.688 MW). The dynamics over the years (cumulative total) is presented in Fig. 1.1.

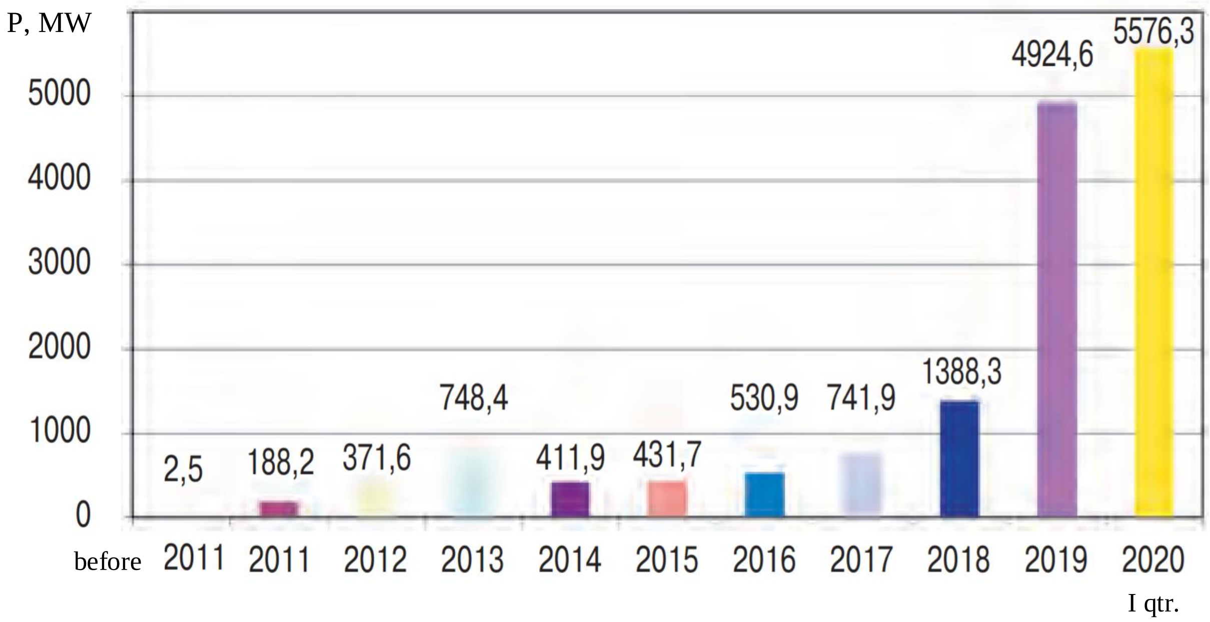


Fig. 1.1 The capacity of industrial SPP installed in Ukraine, cumulative total [4].

The figure shows that in 2019 alone, the capacity of industrial SPP was put into operation 3.5 times more than in all previous years.

As for the smaller amount of electricity produced by industrial stations (Fig. 1.2), in 2019 it will be 2932.37 million kWh, which is 2.66 times the same figure for 2018 (1101.16 million kWh) year.

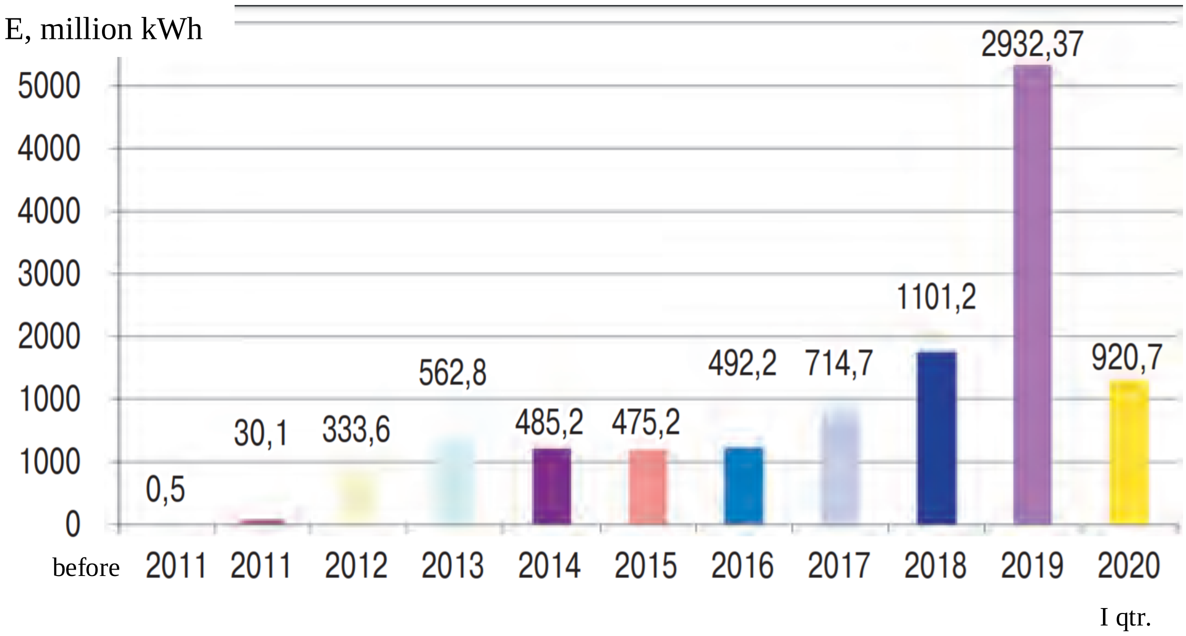


Fig. 1.2 Volume of electricity generation by industrial SPP by years [4].

At the same time, based on the estimated value of the average annual consumption per household equal to 2000 kWh, the energy produced by SPP is sufficient to meet the needs of 1.466 million households.

Detailing statistics. The data published by the National Commission for Regulation of Economic Competition allow for statistical processing of information and receives more detailed characteristics in the field of solar energy.

Thus, in 2019, 494 objects received the "green tariff", of which 382 - ground SPP and 112 - stations located on the roofs and facades of buildings. The SPP capacity installed in that year was 3537.382 MW. Of these, 114 stations exceeded the 10 MW threshold (Table 1.2), and more than 20 MW exceeded 25 facilities. At the same time, 9 projects implemented in 2019 had a capacity of over 30 MW, and 5 stations - over 50 MW [4].

Table 1.2 – The main characteristics of the commissioned SPP by years.

Year	Installed capacity of SPP, MW	Number of new SPP	Number of stations with a capacity exceeding:			
			10 MW	20 MW	30 MW	50 MW
2019	3537,382	494	114	25	9	5
2018	645,688	162	16	3	1	0
2017	211,016	63	3	0	0	0

For comparison, the same table also shows the results of previous periods, which are not so impressive. Thus, in 2018, only 162 industrial facilities received the "green tariff", of which only 16 SPP exceeded the threshold of 10 MW (which is 7.1 times less than in 2019). The data for 2017 are not subject to any comparison at all.

It should be noted that the average capacity of industrial SPP in 2019 is 7.16 MW, which is 3.17 MW (79.4%) higher than in 2018.

Obviously, the average value of the parameter characterizes only one aspect of the implementation. To obtain the structure of project distribution, it is necessary to analyze all implementations in 2019 and identify 493 units. Fig. 1.3 shows the distribution of the number of projects that fall into certain capacity ranges.

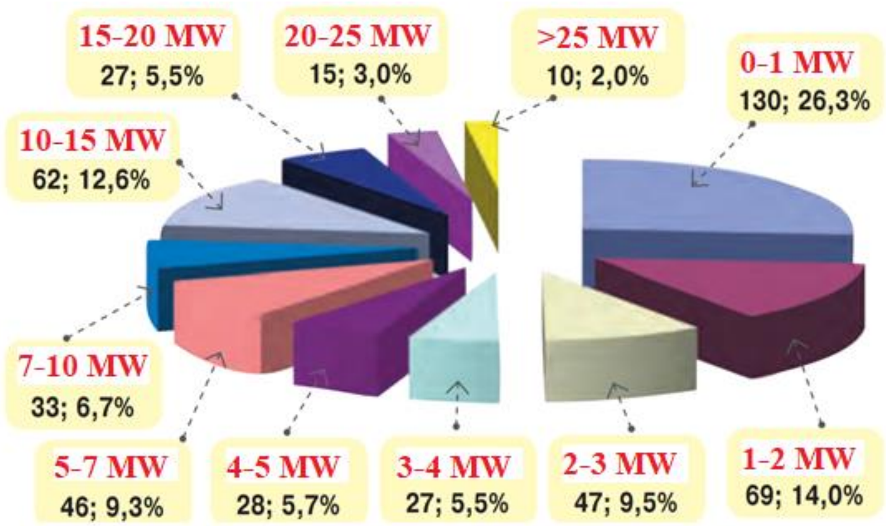


Fig. 1.3 Distribution of industrial SPP projects in 2019 by capacity ranges (in quantitative terms) [4].

The diagram shows that the range up to 1 MW contains 26.3% of facilities (130 SPP). 106 solar stations have a capacity of 1-3 MW. 62.1% of decisions (301 projects) fall in the range of 0-5 MW. In general, 98% of the implementations made in 2019 do not exceed 25 MW. And only 2% (10 projects) exceed this threshold.

Also interesting is the histogram of the SPP distribution by the total capacity of projects that fall into fixed width ranges - in this case, set a step of 5 MW (Fig. 1.4).

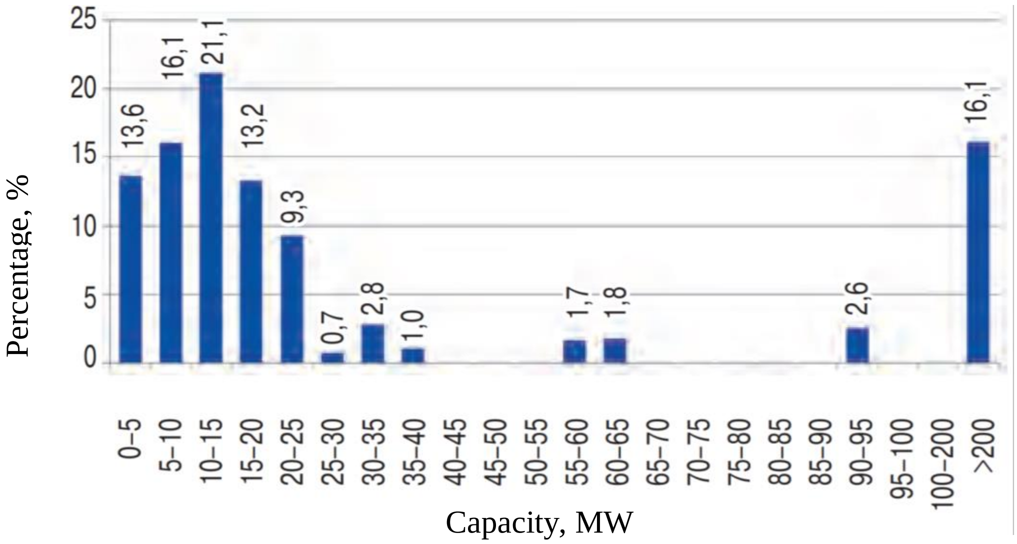


Fig. 1.4 Histogram of the industrial SPP projects distribution in 2019 by installed capacity [4].

According to the results of this work, the largest weight is the interval of 10-15 MW, the share of which in the total energy balance of industrial SPP in 2019 amounted to 21.1%. In second place efficiency - segments 5-10 MW and more than 200 MW, covering 16.1% (in this quantitative cooperation, otherwise for as many as 2 stations). Interestingly, the 5-10 MW column, which also accounts for 16.1%, contains 79 projects. This means that the total capacity of SPP, the indicators of which fit in the range of 5-10 MW, increases the capacity of stations, the nominal value of each of which exceeds 200 MW.

Territorial structure of industrial SPP. The situation regarding the territorial distribution of industrial solar stations put into operation in 2019 is as follows (Fig. 1.5).

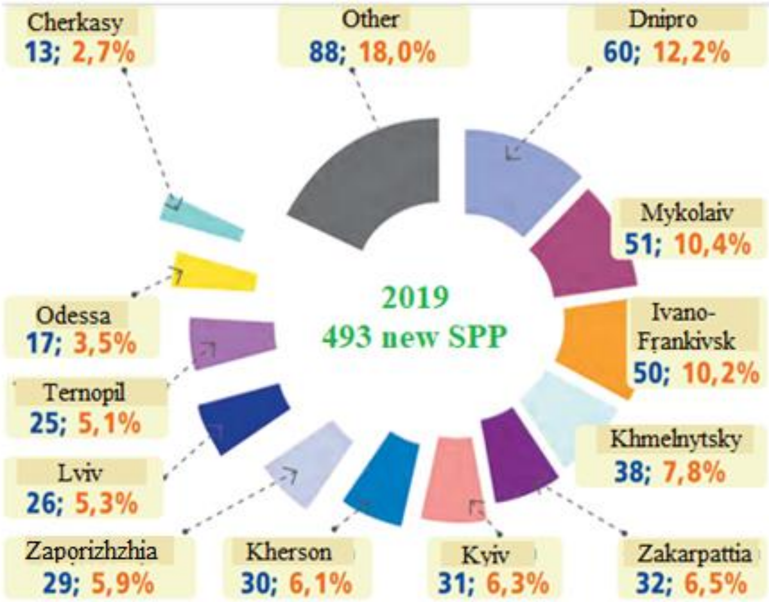


Fig. 1.5 The structure of the number of industrial SPP distribution by regions that received in 2019 a "green" tariff [4].

In quantitative terms, the leader in terms of industrial solar power plants put into operation in 2019 was Dnipro region (60 facilities, or 12.2%). The second and third places are shared by Mykolayiv and Ivano-Frankivsk regions with indicators of 10.4% and 10.2%. The third position in the Khmelnytsky region - 7.8%

The structure of the projects distribution by installed capacity is shown in Fig. 1.6.

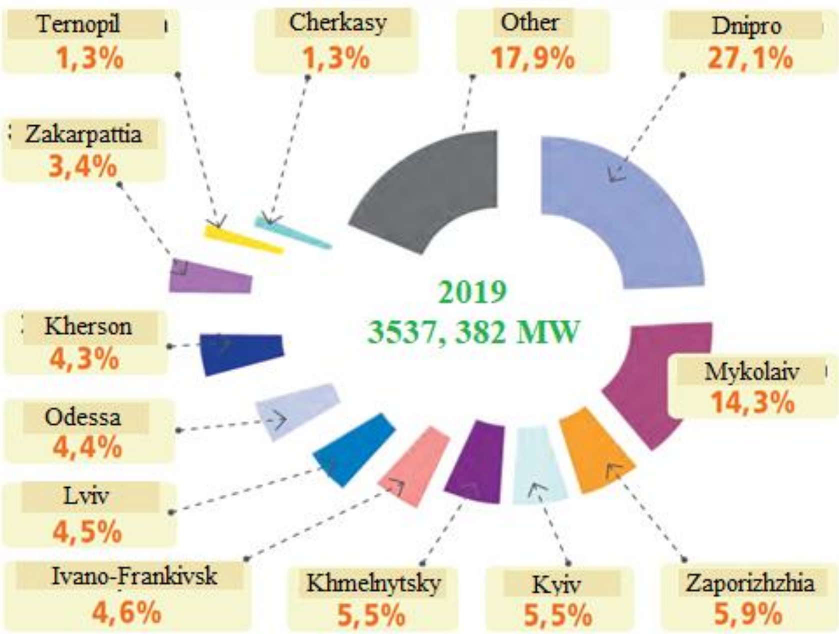


Fig. 1.6 The structure of the industrial SPP distribution by regions (by installed capacity), which received in 2019 a "green tariff" [4].

Due to the commissioning of two large facilities in the Nikopol district ("Pokrovskaya" and "Nikopolskaya" SPP), the Dnipro region came out on top with a large gap with a share of 27.1%; in 2018, it occupied only the 5th position. The second place is the Nikolaev region where the total capacity of the implemented projects makes 14,3%.14.3%. On the third step of the pedestal - Zaporizhzhia region (5.9%). Khmelnytsky and Kyiv regions share the fourth and fifth places with equal shares of 5.5% each. Khmelnytsky and Kyiv regions share the fourth and fifth places with equal shares of 5.5% each.

Leaders of 2019 in terms of installed capacity. The largest industrial solar station put into operation in 2019 was Pokrovskaya SPP (Dnipro region, Nikopol district) with an installed capacity of 323,290 MW (Fig. 1.7).

Fig. 1.7 Pokrovskaya SPP with a capacity of 323,290 MW was built by DTEK VDE in the Nikopol district of the Dnipro region [4].

The facility is serviced by Solar-Pharm-3 LLC. It houses more than 873,000 panels manufactured by the Chinese company Risen, 96 KSTAR inverter systems, as well as power equipment of the German concern Siemens. The total investment in construction amounted to 193 million euros.

The Pokrovskaya solar power plant is located next to the Nikopol SPP in the Dnipro region, on the site of a used ore quarry (437 hectares), the land of which is unsuitable for agriculture. The construction involved 16 companies that received orders worth 48 million euros. It took about 6 months from the start of construction to the commissioning of the facility. Already in October, SPP began to produce "green electricity".

On the second position - "Nikopol" SPP (LLC "Solar Pharm-1") with a capacity of 246,154 MW, built by "DTEK VDE" also near Nikopol (Fig. 1.8).

Fig. 1.8 Nikopol SPP with an installed capacity of 246,154 MW in the Dnipro region is owned by DTEK VDE [4].

The total investment is 216 million euros. The facility is equipped with 750,000 panels made by the Chinese companies Seraphim and Trina Solar, as well as KSTAR inverters. This SPP was included in the preliminary review (Networks and Business, №3, 2019).

The third place in terms of installed capacity was taken by Morozivka SPP, owned by Sanvin 5 LLC (Kropyvnytsky region, Oleksandriiskyi district, Novoselivska village council) - 91.287 MW. More than 243,000 Risen solar panels and 28 inverters were used at the site. The station received a "green tariff" on December 24, 2019.

On the fourth position is the project of Kamyanets-Podilska SPP (Fig. 1.9), Khmelnytsky region, Kamyanets-Podilsky district, on the territory of Panivetska agriculture.

Fig. 1.9 Kamyanets-Podilska SPP with a capacity of 63.8 MW was put into operation in January 2019 [4].

The station belongs to PE "Podilskenergo". Its capacity is 63.8 MW. The investors of the project on a parity basis were the ICU Group and the investment fund VR Capital Group, investing $ 55 million in the project.

The Kamyanets-Podilska solar power plant is located in the Kamyanets-Podilsky sugar plant filtration fields, which are currently not suitable for agriculture. The station is equipped with 220,000 single-crystal Longi Solar modules (China), as well as ETD power transformers (Czech Republic). KNESS was the general contractor for the construction. More than 50% of the station components are manufactured at Ukrainian enterprises. SPP covers an area of 110 on, its construction lasted 7 months.

The fifth position is occupied by the SPP project in Chernivtsi region, Novoselytskyi district, village Tarasivtsi, Shipot tract (Fig. 1.10).

Fig. 1.10. SPP near the village Tarasivtsi, Chernivtsi region with a capacity of 58.78 MW [4].

This station is owned by Ekotekhnik - Tarasivtsi LLC. Its capacity is 58,776 MW. During the construction, 833 Huawei SUN2000–60KTL-M0 inverters were used, as well as 209,916 Talesun solar panels. The station is built on swampy, unsuitable for agriculture lands with a total area of 108 hectares between the villages of Tarasivtsi and Vanchykivtsi.

Leaders of 2019 in electricity production. Among the winners are both objects of previous years and SPP of the studied period. The victory was won by the station "Nikopolska", the production of which is 282.606 million kWh. In second place - 10 launch complexes in Tokmak, which are presented in the statistics of the National Commission for Regulation of Economic Competition in a single total column - 72.349 million kWh. The third position is occupied by Kamyanets-Podilska SPP with a rate of 71.674 million kWh. Fourth place at Voskhod Solar station - 68.045 million kWh. On the fifth step – Yavoriv SPP (49.371 million kWh), consisting of two complexes, one of which received a "green tariff" in 2019.

All leaders of the electricity generation industry in 2019, which exceeded the threshold of 30 million kWh, are presented in Table 1.3.

Table 1.3 – Leaders of 2019 in the production of solar electricity.

Name of SPP and location	Amount of electricity generated in 2019, million kWh	Installed capacity, MW
Nikopol SPP, Dnipro region, Nikopol district, Suburban and Chkalovsk village councils	282,606	246,154
Tokmak SPP in the Zaporozhye region,	72,349	64,15 (10 launch complexes)
Kamyanets-Podilska SPP, Khmelnytsky region, on the territory of Panivetska village	71,674	63,800
Voskhod Solar SPP, Berezanka township, Mykolaiv region	68,045	53,398
Yavoriv SPP, Lviv region, Yavoriv district, village Ternovitsa	49,371	36,753 + 35,101 (2019 p.)
Bolgrad Solar SPP, Bolgrad district, Odessa region	44,901	34,14
Priozerne 1 SPP, Kiliya, Odessa region	37,611	27,356
Priozerne 2 SPP, Kiliya, Odessa region	37,289	27,488
Neptune Solar SPP, Voznesensky district, Nikolaev region.	36,558	29,307
Kherson SPP, Kherson City Council	33,046	34,758 (2 start-up complexes)

Thus, the generation of electricity by industrial solar power plants in 2019 almost three times exceeded the corresponding figure of Kakhovka HPP (Hydro Power Plant).

Projects of the beginning of 2020. According to the statistics of the National Commission for Regulation of Economic Competition, which also contains data on industrial solutions in the field of solar energy, on June 1, 2020 in our country "green tariff" received 174 new SPP, of which 99 - ground and 75 - installed on the roofs and walls of buildings and structures. The total capacity of these SPP is 686,016 MW or 12.2% of the total figure determined for the country on that date (5610,611 MW).

Since the implementation in 2020: 22 stations have a capacity exceeding 10 MW, 6 facilities have exceeded the threshold of 20 MW, and four more have exceeded 30 MW. The largest SPP for the first 5 months of this year were two stages of Ingulets SPP - Mykolaiv region, Snihuriv district, the territory of Afanasievskaya agriculture, the total capacity of which is 57,552 MW.

The owner of the object is Ingulets-Energo 2 LLC. The construction of the station was financed by the European Bank for Reconstruction and Development (EBRD) and the Black Sea Trade and Development Bank (BSTDB), which provided 19.1 million euro each. The SPP designer is Podilsky Energoconsulting, the general contractor is Soyuz Corporation.

In second place - Boguslav-2 SPP (Kyiv region, Boguslav district, Boguslav), the installed capacity of which is 54,264 MW (Fig. 1.11).

Fig. 1.11 Boguslav-2 SPP with an installed capacity of 57,552 MW near the city of Boguslav in the Kyiv region [4].

The project was implemented by the Norwegian company Scatec Solar. The commissioning of this facility was supported by the LCF Legal Group Currently, solar panels cover an area of 65.84 hectares. The system consists of 142.8 thousand modules and 450 inverters. The designer was Rodina Engineering LLC, the general contractor was Scatec Solar Solutions Ukraine LLC.

The third place was taken by Solaris-Energy SPP, Zakarpattia region, Vynohradiv district, village Shalanki - 34,557 MW. The final beneficiary is UG POWER (Great Britain). Building area - 19.35 hectares, the number of solar panels - 104,720, inverters - 10.

Considered the industry as a whole, the largest SPP in Ukraine (as of 01.06.2020) are represented by facilities (Table 1.4), the installed capacity of which exceeds 50 MW.

Table 1.4 – The largest industrial SPP of Ukraine as of June 1, 2020.

Name of SPP and its location	Installed capacity, MW	Date of receipt of the green tariff
Pokrovskaya SPP, Dnipro region, Nikopol district	323,290	September 6, 2019
Nikopol SPP, Dnipro region, Nikopol district	246,154	February 28, 2019
Yavoriv SPP, Lviv region, Yavoriv district	71,854	October 30, 2018 (first stage), October 11, 2019 (second stage)
Zaporizhzhia region, Tokmak	64,15	2017–2019
Kamyanets-Podilska SPP, Khmelnytsky region, on the territory of Panivetska agriculture	63,800	January 11, 2019
Ingulets SPP, Mykolaiv region, Snihuriv district, territory of Afanasievska agriculture	57,552	January 3, 2020 (first and second turn)
Boguslav-2 SPP, Kyiv region, Boguslav district, Boguslav city	54,264	February 21, 2020
Voskhod Solar SPP, Berezanka township, Mykolaiv region	53,398	February 20, 2014

Thus, 2019 demonstrated the rapid evolution of the segment of industrial solar stations. However, for the period of 2020, given the economic decline due to the pandemic, the development of solar energy also stopped.

Solar generation, as a component of renewable energy, will definitely come out of the crisis in our country and continue its evolutionary progress [4].

1.4 Existing methods of providing warranty power supply systems

Consider the definition of electric receivers of the I category and special group and the requirements for their power supply [5].

Category I electric receivers are such electric receivers, the interruption in the power supply of which can cause danger to human life, significant damage to the national economy, damage to valuable basic equipment, mass shortage of products, disruption of complex technological processes [6].

From the category of electric receivers of the I category the special group of electric receivers which uninterrupted work is necessary for accident-free stop of production for the purpose of prevention of threat to life of people, explosions, fires and damage of the valuable basic equipment is allocated. [5].

Reliability category I power receivers must be supplied with electricity from two independent mutually redundant power sources, and a power outage in the event of a power failure from one of the power sources may last only for the time of automatic power recovery.

For power supply of a special group of electric receivers of the I category additional power supply from the third independent mutually reserve power supply source should be provided [6].

As the third independent power supply for a special group of electric receivers and as the second independent power supply for other electric receivers of the I category can be used local power plants, power systems of power systems, special uninterruptible power supply units, accumulators, diesel power plants, etc. [5].

It is allowed, as an exception, to extend the requirements for the reliability of electricity supply of higher category electric receivers to lower category electric buildings of a house or building on the initiative of the owner in coordination with the transmission company, so the whole complex of category I consumers and special group.

One of the main options for implementing a guaranteed power supply is to reserve power to industrial facilities. The topic of such objects reservation of is considered by E.O. Antipov in the work “Combined power supply system for consumers using traditional and alternative energy sources and accumulators” [7].

A new system of combined energy supply of consumers has been developed, which is based on the use of solar radiation energy and/or electric network with the possibility of accumulating its excess in batteries of electric and thermal energy. This system is designed to cover the electrical and thermal load of the consumer with increased economic efficiency of heating and/or hot water systems through the use of solar energy and heat storage.

The disadvantage of this system is its cost, because this aspect significantly affects the feasibility of its use. The high cost is due to the large number of equipment and the complexity of the system.

The issue of providing backup power is widespread not only for industry or household consumers. The main area of such systems implementation is power plants, namely the backup power of technological mechanisms of their own needs. Due to obsolete equipment used as backup devices, its inclusion requires a lot of physical and mechanical costs. Since most switching of the reserve of own needs of power plants is not carried out automatically, the untimely operation of the reserve can have many negative consequences. One of the main is the long pause of power supply of technological mechanisms of own needs with their unsuccessful start of electric motors in the automatic mode. In this case, there is a possibility of stopping one or more power units. The consequences of which can be deployed within the entire integrated power system of Ukraine.

On the example of joint work of Dmitrenko O. O. and Zakolodyazhny V. V. on the topic: "Automatic transfer switch of the backup power line of the nuclear power plant's own needs", it is possible to consider introduction of automatic transfer switch (ATS) for own needs of Zaporizhzhia nuclear power plant (NPP) [8].

In this paper, the researchers proposed an algorithm for the automatic start of the load for the basic scheme. This circuit includes switching on the sectional switch of the reserve line when the rated voltage drops or disconnecting the working input of the reserve power of the transformer of own needs.

The redundancy system is proposed on the basis of a combination of two main power transformers in working condition and one in reserve mode. Automatic load switching should turn off the feeder input (if it is still connected) and turn on the sectional switch.

Automatic load switching works on the basis of the ARGON automatic transfer system, which allows to increase the level of information equipment of the

Zaporizhzhya NPP personnel through the use of modern microprocessor, digital and discrete devices. The system also allows to increase the reliability of the NPP's own needs, to reduce the time of power drop and significantly reduce the cases of emergency switching devices of backup power lines.

The main disadvantage of this system is the possible asynchronous switching of different backup power transformers on one bus. Such switching can lead to a specific system failure and overload [8].

Conclusion to Section 1

In this section, an analysis of guaranteed power supply systems was performed and the existing methods and classifications of such systems were considered. In addition, an analysis of the legal framework on consumer reliability was conducted. Based on the analysis, I can conclude that the issue of security is quite relevant not only in the scale of industry or the life of each consumer, but in general for the integrated power system. As a backup source, many resources can be used, one of which is solar energy.

An extensive analysis of existing industrial stations, which became the basis for further development, was conducted. At the moment, Ukraine has been able to show that the rapid growth of RES development can be realized only with the right tasks and sound actions to implement them.

2 FORMATION OF THE SUPPLY GUARANTEE SYSTEM WITH A COMBINATION OF THE POSSIBILITIES OF TPPs AND SPP

2.1 The structure of the power plant and power system

The type of power plant is determined primarily by the type of natural energy. The most widespread are thermal power plants (TPPs), which use thermal energy released during the combustion of fossil fuels (coal, oil, gas, etc.). Thermal power plants produce about 76% of the electricity produced on our planet. This is due to the presence of fossil fuels in almost all parts of our planet; the possibility of transporting fossil fuels from the place of extraction to the power plant, which is located near energy consumers; the possibility of using the heat of the working fluid, which has worked out and the release to consumers, in addition to electricity, as well as thermal energy (with steam or hot water), etc. [9].

Power plants, power lines, substations, installations that consume electricity are interconnected by a common mode of continuous process of production, distribution and consumption of electricity.

Combining power plants into power systems increases the reliability and efficiency of energy supply. The use of reserve capacity of individual power plants in other areas of the power system reduces the total reserve and increases the reliability of energy supply. The simultaneity of the maximum load in areas with different longitudes reduces the total (combined) maximum load and the required operating capacity of power plants in the power system. The possibility of rational load distribution between power plants and power systems contributes to fuel economy. Power systems also include heat supply installations and heating networks [9].

Energy management includes installations for the production, transmission and use of electricity and heat.

Energy management is directly related to fuel and transportation, including devices for extraction, processing and transportation of fuel.

Fuel and energy farms together form a fuel and energy farm.

2.2 Classification of thermal power plants

The type of thermal power plant (TPP) on fossil fuels is determined by the following factors.

According to the type of energy released, thermal power plants are divided into:

- condensing power plants (CPP) - with steam condensing turbines, releasing energy of one type - electric;
- combined heat and power station (CHP), which supply electricity and heat with steam or hot water to external consumers.

According to the nature of heat consumption, there are CHPs:

- industrial type, with the release of steam to enterprises for technological processes;
- heating type, with heat release usually with hot water for heating and ventilation of houses and for household needs of the population;
- industrial and heating type, with release of steam and hot water for technological and heating needs [9].

There are thermal power plants on solid, liquid and gaseous fuels, on two or all three types of fuel. At present, liquid (fuel oil, rarely crude oil, usually high-sulfur) and gas (natural gas) are widely used at thermal power plants along with solid fuels (coal and lignite, etc.). The transition to liquid and gaseous fuels greatly simplifies and reduces the cost of thermal power plants. The use of natural gas also contributes to the cleanliness of the air basin.

By type of turbines to drive electric generators. There are thermal power plants with steam (ST) and gas turbines (GT).

The efficiency of modern steam turbines reaches 40%, gas turbines - not more than 28-34%. At steam turbine of thermal power plants it is possible to use any type of fossil fuel (coal, shale, peat, fuel oil, gas). Gas or liquid fuels are mainly used at gas turbine thermal power plants [9].

The values of the pair initial parameters and the type of thermodynamic cycle are divided into a number of characteristics.

According to the level of the initial pressure of fresh steam, there are power plants with up to critical (usually below 16.0 - 17.0 MPa) and supercritical (above 22 MPa) steam pressure.

Drum steam generators with natural circulation (type E) or direct-flow steam generators (type P) are installed at power plants with subcritical pressure. The use of direct-flow steam generators is necessary at critical and supercritical pressure of fresh steam. The lower the vapor pressure, the less advantage is given by direct flow boilers.

Regarding the type of the main technological scheme, TPPs are divided into block and non-block. Modern condensing power plants, which usually use intermediate superheating of steam, perform a block type.

With the block structure of the TPP, each turbine is powered by steam only from the adjacent steam generator (monoblock), sometimes from two steam generators (double block) [9].

Connecting pipelines of steam of fresh and intermediate overheating, nutritious water between blocks do not carry out. TPPs with such schemes are cheaper, easier to control and automate. CPP with an initial pressure of 9 MPa and below and CHPs with a pressure of 13 MPa and below (both without intermediate superheating of steam) usually have a non-block structure, in which fresh steam and feed water lines are common to all steam generators. Steam turbines are powered by steam from these common mains.

It is possible to conditionally divide thermal power plants into power plants of large (over 1000 MW), medium (100-1000 MW) and small (less than 100 MW) capacity. The largest capacity of TPPs is usually limited by local conditions (fuel supply, water supply conditions, nature protection requirements - maintaining the cleanliness of air and water basins) [9].

In the CIS, as well as in other industrialized countries, power plants tend to operate in power systems. "Isolated" power plants outside the power system are increasingly becoming an exception. Initially built in the newly developed peripheral areas of the country, they are later also included in the energy system.

Regarding the degree of loading and use of electric power of thermal power plants are divided into:

- basic, with annual use of maximum (installed) capacity: T_{max} = 6000…7500h.;
- semi-basic: T_{max} = 4000…6000h.;
- semi-peak: T_{max} =2000…4000h.;
- peak: T_{max} up to 2000h.

Power plants with better energy equipment and better energy performance are loading more. One power plant can have different units (power units) with different degrees of perfection. Accordingly, they are loaded differently, this division also applies to individual units (power units) [9].

2.3 Features of TPP energy consumption

Consumption of electric and thermal energy changes over time: during the day, week, year. The electrical load of TPPs includes, in addition to the main value, - the release of energy to consumers, electricity losses during transport, as well as the own cost ("own needs") of the power plant.

The graphical representation of the change in the load of the TPP over time is called the load graph.

Daily load schedules have the greatest importance for power systems and power plants: winter, summer, spring and autumn, per working day, at the beginning, middle and end of the week; for a non-working day. The main consumers of electricity are industrial, lighting and utilities [9].

The form of the daily schedule of electric loading depends generally on a season, a parity of electric consumption by industrial and lighting and household installations, on number of changes of work of the industrial enterprises for days.

The schedule of industrial load is characterized by a maximum during the day, when all enterprises work - with one, two and three shifts per day. Characteristic are: rapid rise of the load in the morning, the maximum load during the day with a temporary decrease ("failure") of about 12 hours in the afternoon due to the lunch break of the day shift, a significant decrease in the load at night.

Winter daily schedule of lighting and household load has not a large maximum in the morning, before work, and the main maximum in the dark, about 16 hours, in December-January.

Industrial summer load is slightly lower than winter, mainly due to the removal of part of the equipment of enterprises for repair. Lighting and household load in the summer has a slight increase in the morning, and in the evening its maximum occurs later - up to 20 - 22 hours. Therefore, the maxima of industrial and lighting loads in summer do not coincide in time, and the total load after 16 hours first decreases, increasing again with the inclusion of lighting[9].

As a result, the winter load has two maxima — morning and evening, due to a combination of industrial and lighting loads; the corresponding graph is figuratively called "two-humped".

Summer workload has three maxima — morning, daytime (after lunch break), and evening workload, when workloads of two- and three-shift industrial enterprises are combined with lighting and household. The summer schedule of electric load is figuratively called "three humps"[9].

2.4 Basic technical and economic requirements for thermal power plant

The main requirement for a power plant is reliability. Reliability - uninterrupted production of electricity in accordance with consumer demand and dispatch schedule. Power units must be maneuverable to meet fast-changing loads. Maneuverability - the ability to quickly dial and remove the load, quick start from idle and stop, without compromising reliability and durability. In this case, according to the Rules of technical operation of power plants (RTO), the frequency of electric current in power systems must be continuously maintained at 50 Hz with deviations of not more than ± 0.1 Hz, temporarily not more than ± 0.2 Hz. The frequency is regulated in the combined (single) power system by one of the power systems, in the isolated power system - by one of the power plants.

High reliability should be laid in the equipment and lines of communication at their designing and installation, in the project of power plant as a whole and should be supported by long-term high level of culture of operation, timely and careful repair. However, even if these requirements are met, the probability of equipment failure and an accident is not excluded. Reliable power supply of consumers is provided at the same time by additional reserve units and power units.

Heat supply to consumers must also be uninterrupted. This primarily refers to the supply of steam to industrial enterprises, especially those whose technological process (refineries, etc.) must be carried out continuously.

The second main requirement for power plants is efficiency. Two types of economy - construction and operation are partly consistent with each other, partly contradictory. Production costs include, in particular, deductions from one-time costs (capital investments) for depreciation of equipment (renewal of its operability during operation), as well as structures. These deductions are greater the more expensive the power plant. At the same time, the main component of TPP production costs is the cost of fuel. Fuel and cost savings are achieved by technical improvement of equipment and, as a rule, its rise in price.

2.5 Main problems of TPP operation

In the modern power system of Ukraine, a large share of thermal generation is used partially or completely decommissioned, as well as preserved. This problem is due to insufficient funding for equipment upgrades, so the capacity of TPPs in these realities is much less than was found in the design of lines and transformer substations that connect generation to the power distribution unit [10].

The catastrophic state of the industry, the underfunding of energy companies, the state of equipment beyond what is acceptable, non-payment of wages to miners, the million-dollar needs of the industry, which are postponed for years so that the population receives cheap electricity and heat, hidden non-tariff monetary and socio-environmental costs for providing/maintaining traditional methods of energy production and production of electricity and heat – this is how the current state of the traditional energy industry can be described [10].

The technological process of obtaining electricity (and heat) from "traditional" fossil fuels (coal, uranium and natural gas), in progression will require more and more money and non-money costs, and therefore over time will inevitably cost society more, and land.

It is more and more difficult and expensive to extract fuel, which due to its fundamental exhaustion lies deeper, the more it is extracted, and more and more complex layers will have to be developed and, consequently, more financial costs will have to be extracted.

It is increasingly difficult and expensive to avoid or neutralize (unfortunately, only partially) the consequences of harmful environmental impacts on nature.

More and more water reserves (so scarce in today's world) are consumed by traditional types of generation, which will continue to grow exponentially (in Ukraine, against the background of natural resources for water and natural resources, the problem is not so noticeable and only gaining momentum) and inevitably leads to a conflict on the one hand the needs of mankind in water for domestic consumption and food production, and on the other hand - the needs of the same humanity in electricity [10].

Unpredictable man-made impacts on human health, animal husbandry and agriculture in general are becoming more widespread.

Increasingly expensive repair, modernization and emergency repair work on worn, "patched " domestic energy facilities.

Non-tariff public expenditures to maintain the possibility of further operation of "cheap" traditional electricity generation from coal and uranium are growing every year.

The most unprofitable mines will have to be closed (which is, by the way, not a cheap pleasure, which is financed, including from the state budget). The coal industry is becoming uncompetitive (for comparison: electricity from renewable sources, such as SPP, is becoming cheaper over time, ensuring the payback of not only large but also small projects of private households) [10].

The problem of global scale is extensive and partially irrational hyper-consumption of water resources by traditional energy enterprises. If translate the amount of electricity needed by mankind into the amount of water consumption, the size of the so-called "water footprint" (the volume of water required to make 1 kW) is growing just phenomenally. The World Economic Forum recently ranked the water crisis as one of the biggest global risks for the next 10 years. At the same time, one of the most water-intensive spheres of human activity is carbon and nuclear power generation. The production of electricity consumes five times more water than for household needs (drinking, cooking, washing, washing dishes, sanitary needs), and about as much more than in industry. The energy sector consumes almost the most water - the greatest value of mankind, at a time when the world is facing the threat of global droughts and water scarcity in vast populated regions. If politicians around the world do not take into account the relationship between energy and water, in many parts of the world, access to water will be the determining factor for electricity supply. This, in turn, will force governments to urgently allocate scarce water supplies between traditional energy (TPPs, large hydropower plants, nuclear power plants), food production, industry, health care and general sanitation. Unlike traditional energy sources - RES either do not require water consumption at all, or incomparably less.

The inevitable inertial choice of Ukrainian government officials is already focusing the country on the development of traditional industries, including nuclear power plants. It is important to realize that the widespread opinion about the "cheapness" and safety of nuclear generation - a myth, and at the first steps in this direction in parallel in the coming years it will be necessary to find (take out of our pockets, through payments, the budget or something else) funds, commensurate with the cost of construction or modernization of units. Funds will also need to be used to close spent units and to build their own spent nuclear fuel storage facilities. If the technologically competent decommissioning of nuclear units is not carried out (the vast majority of which have already passed the procedure of extending the regular service life and the second time such extension is hardly possible), the consequences may not be foreseeable. It is no coincidence that the formerly powerful countries of nuclear energy are purposefully abandoning nuclear power plants today, for example, the governments of Germany and Canada have announced plans to completely stop the production of electricity at nuclear power plants by 2020[10]..

Global trends record a steady and progressively increasing trend towards lower prices for electricity produced from renewable energy sources, which will continue to decline, because in their composition, in addition to the initial investment in equipment, there is no fuel component (decisive in the current tariffs for traditional energy). In addition, RES either does not have at all or causes disproportionately lower non-price public costs to maintain environmental safety. Also, the process of approximating the production characteristics of RES to the requirements of energy systems for full-fledged scheduling is in full swing. Thus, from an auxiliary and alternative energy source, becoming the main one, suitable for providing not only the household, but also the whole region or city with a reliable, sustainable and secure electricity supply. At the same time, it works on RES, because every year the technological processes and scientific and engineering base of production become cheaper and better [10].

It should also be emphasized that today the construction of each new 1 W of installed capacity of traditional energy - exceeds the cost of construction of RES. Now Ukraine is sufficiently dependent on imported energy sources: gas, coal, nuclear fuel supplies. To strengthen the country's energy security, it is important to make a choice: continue to finance external energy sources or still develop the use of its own energy sources, while increasing the contribution of "green" electricity to Ukraine's energy independence[10].

2.6 Power control for industrial SPP

2.6.1 Reactive power control methods

Reactive power control is an integral part of voltage control in the power system. At low load, the system generates reactive power that must be absorbed. At the same time, at high loads, the system consumes a large amount of reactive energy that needs to be generated [11].

Traditional synchronous generators, which are widely used in domestic networks, qualitatively maintain the balance of the reagent, but the cost of this method of compensation is relatively high. To maintain the parameters of the power system, companies often use static compensation units, in which, depending on the current situation, either capacitors or inductors are connected to power lines.

The main disadvantages of this method:

- reaction too slow (from a few seconds to a few minutes);

- discreteness of elements that does not ensure the completeness of the compensatory effect;

- voltage and current jumps through transients at the moment of switching on or off of discrete modules.

To solve the problem, designers of power systems install synchronous compensators, static VAR compensators (SVCs) and static synchronous compensators (STATCOMs) in all nodes of the network, where fast and smooth control of reactive power is required [11].

Synchronous compensators are the facilitated synchronous motors working at idling. In this mode, they generate only reactive power, and the generation of active power is zero. SVC i STATCOM, in contrast to synchronous compensators, are not structurally synchronous motors, but they belong to the category of dynamic devices due to the high response speed and variable power at the output of the device.

SVC is a combination of conventional capacitors and inductors with high-speed switches (usually semiconductor controlled semistors), which allows you to control more smoothly than static batteries. STATCOM - solid-state power electronic devices, such as solar inverters, but located outside the array of a solar power plant. They are able to absorb and generate reactive energy by changing the voltage, the numerical value of which will be more or less voltage on the common bus. Given that the cost of inverters is falling three to four times faster than the cost of traditional reagent compensators, their use for these tasks is growing every year and in the long run they will completely displace other compensation units [11].

2.6.2 Distributed electricity generation

The solar power plant has many photovoltaic inverters connected to a common bus. As mentioned above, each of them can both absorb the reactive component, counteracting the voltage increase at the point of connection, and generate it, fighting voltage dips. With a fairly high integration of solar power plants and power distribution networks, it is possible to build systems that will combat the voltage spikes that inevitably occur in any large network. Sensitivity to changes in light (and hence generation) in some parts of the network will also be minimal [11].

Thus, it is possible to create a fundamentally new tool (distributed system) that can minimize heat loss from reactive currents and even compensate for the reagent from external consumers. However, for such distributed systems, a large number of work issues have not yet been resolved and their implementation is a matter of the future [11].

2.6.3 Inverter level and enterprise level regulation

When developing a control system, designers can plan the impact of the regulatory action at the level of each individual inverter, or at the level of the solar power plant as a whole. At the power plant level, the central controller controls the reactive power level, power factor or voltage at the node of the enterprise network to the external electrical network [11].

Modern inverters can have several built-in functions, which allow the implementation of the following strategies at the level of inverters:

1. Maintaining a constant power factor. Typically, inverters operate at a power factor equal to one, but they can be adjusted to maintain a lower factor (provided that the set parameter must be in the operating range of the model used).

2. Maintenance of constant reactive power - regardless of the level of active power produced by the system itself.

3. With voltage feedback. In this mode, the coefficients of active and reactive energy are changed by the controller taking into account the current measurements of voltage sensors.

4. Dynamic setpoint control. The inverter adjusts the setting of the power factor or reactive power level depending on the signal received from the manager.

If consider the industrial solar power plant as a whole, it can consist of dozens or even hundreds of photovoltaic generators. The central controller will coordinate the work of individual inverters and turn them into a single virtual generator. In this case, the controller commands will be transmitted through the SCADA program, or in another cheaper way (for example, through a remote terminal) [11].

This control mode is especially useful for the transfer of energy between interconnected solar power plants, which must operate in voltage control mode - the controller will constantly change the reactive power of the inverters, depending on the situation, thus maintaining the voltage at a constant level.

When designing a system that regulates the power system at the enterprise level (power plant) it is necessary to understand that the central controller is a critical equipment. In the event of a malfunction or in the event of a software failure, any control over the inverters or the power transmission system will be lost, moreover, throughout the enterprise. Therefore, it is necessary to duplicate all systems - the server and the devices feeding it, the data transmission equipment, etc. And at the first best opportunity it is necessary to design local control subsystems which will be able to carry out at least some functions of the central processor at its malfunction or unavailability.

In addition to inverters, other types of equipment can be used to control and regulate reactive power, especially if the use of inverters will reduce the power output. Thus, the developer of system can stop the choice on the switched capacitors and compensators. Such a replacement requires economic justification and calculation of the ratio of changes in the cost of electricity and the amount of capital contributions [11].

But before considering such options, the designer should think about a possible combination of static and dynamic devices. It may well be economically feasible to roughly adjust the reagent using switchable capacitor banks and fine-tune the inverters. The presence of pulse switches will increase the parasitic transients at the time of connection and disconnection of capacitor banks, which require more powerful and high-quality dynamic control systems. However, reducing the total cost of the project (static devices in the general case are significantly cheaper than dynamic with similar characteristics) will allow you to buy dynamic systems of higher quality [11].

2.7 Analysis of the possibilities of combining TPP and RES

The first question is the balance of power at the point of connection of the station to the network (at the point of input of power). The total power that will be generated by the combined sources should not exceed the line capacity at any time. But the value of power in the line should be as close as possible to its capacity in order to operate it most productively.

The condition of optimality is also the cost indicator of the spent primary energy resource per kW of generated energy. And the needs of the market in which the generating company operates, namely in the market for the day before, the intraday market and the balancing market.

The ability of TPPs to dynamically and smoothly change the schedule of its generation according to the needs of the power system also opens up opportunities for its combined use on common buses with other energy sources. A part of thermal generation capacity deduces at the moments of electric energy consumption from SPP from work. This is possible due to the peculiarities of the above generating stations. At the moments when the energy from the SPP enters the network, the load of the TPP lines is reduced by a proportional number, that is, in the same period it is possible to enter through the same line of SPP capacity.

With the help of thermal generation it is also possible to solve the problems that arise due to the uneven generation of SPP. Because the generation of SPP is stochastic in nature and changes dramatically due to cloudiness, which is difficult to predict with a significant lead. With the help of TPP shunting units, it is possible to better adapt to this problem.

Of course, the problem for implementing this option of using combined generation is the fact that most TPPs are located within cities or their environs, and do not have around the free areas to accommodate bulky SPP equipment, and are in regions with low solar insolation.

However, if consider this issue from the point of view of technical feasibility, it is possible to get a number of advantages over the construction of SPP in areas where there are no points for power input:

- no network planning costs for power transmission;
- no costs for the construction of the line itself;
- no costs for the construction of a transformer substation;
- resolved the issue of reactive power consumption;
- the possibility of overlapping stochastic generation of SPP.

2.8 Possibilities of placing SPPs on the territory of TPP

The study is based on information about the work of Burshtyn TPP.

Burshtyn TPP is one of the few stations in Ukraine, some of whose power units operate to export electricity to European countries: Hungary, Romania and Slovakia.

The main fuel is coal from the Ukrainian coal basins, and the auxiliary fuel is natural gas and fuel oil. The total capacity of the station reaches 2400 MW.

In total, nine of the twelve power units operate at the station at the same time, which has an extremely negative effect on the condition of the equipment. This mode requires significant maneuverability (multiple starts and stops of units).

The plant covers the island's domestic energy consumption (approximately 3 million people) and transfers up to 645 MW of energy for export.

Burshtyn TPP covers a total of about seventy hectares and of which about 68.2 hectares is the area of ash drainage. However, the area involved is much smaller, so after the reconstruction it is possible to use a land plot of 32 hectares. All this area is not suitable for use in any of the other options (construction, agriculture, etc.).

For economically feasible use of space for the installation of SPP, solar panels will be on the territory of the ash drain.

The overall potential allows you to install an incredibly large number of arrays of solar panels.

Conclusions to Section 2

In this section, the analysis and classification of thermal power plants as equipment that generates heat and electricity is given. The tendencies of decrease in the use of fossil fuels, in particular coal, are revealed. The main tasks set for the station staff are analyzed and the main ways of realization of these tasks are determined. The main features of operation and production of electricity by different types of stations, in particular TPPs and CHPs, are considered. The impact of the stations on the quality of electricity and balance reliability was also assessed.

Based on the analysis, it can be concluded that due to the maneuverability of the thermal power plant, it is best suited for installation and connection to its system, solar station. Another important criterion is the fact that legislative obligations have been imposed to reduce the production of electricity using fossil fuels, which in turn has led to a reduction in the area used for the ash dump. This territory can be used for installation of SPP.

3 INVESTMENT ECONOMIC ASSESSMENT OF THE PROFITABILITY VALUE AND RETURN OF THE SPP USING NPV AND IRR FUNCTIONS

3.1 The urgency of the issue of SPP economic benefits

Nowadays photovoltaic power plants are the most popular commercial energy source in our country. According to the reports of the National Commission for State Regulation of Energy and Public Utilities (NCSREU), solar power plants take first place (approximately 65%) relative to power. Such great development of PVPS in Ukraine are caused by such factors as accessibility of equipment, favorable economic component (price of the selling) and relatively high level of solar radiation on Ukrainian territory. Economic aspect is the most important today. Most investors focus their attention on the profitability of SPP [12].

Therefore, this project will view 1 MW SPP, which is considered the most significant on the industrial stations market for the sale of electricity at a "green" tariff.

To understand better the economic component of the project, the current stage of development of electricity market regulation in Ukraine will be considered, as well as the internal rate of return (IRR) and net present value (NPV).

3.2 Basic description of current Ukrainian situation (“green tariff”, regulation of the energy market)

The electricity market is regulated by two main Laws of Ukraine on this issue, namely: “On the Electricity Market” and “On Alternative Energy Sources”, as well as some amendments to them.

The Law on Alternative Energy Sources was passed in 2003, but Ukraine began active development in the field of green energy only in 2015 after some amendments to the law. Specifically, after the establishment of “green” tariffs for electricity generated by installations that operate at the expense of solar energy and/or wind energy. “Green” tariffs apply to both private households and industrial installations. The determined tariffs were very high in compare with similar tariffs in other European countries. Therefore, due to the too rapid development of unpredictable renewable energy sources in 2019, much lower “green” tariff rates have already been set for industrial plants:

Table 3.1 – “Green” tariff rates for industrial SPP [13].

	Roof SPP	Ground SPP
From 31.12.2019	0,164 euros per kWh	0,15 euros per kWh
From 01.01.2020 to 31.12.2020	0,123 euros per kWh	0,113 euros per kWh
From 01.01.2021 to 31.12.2021	0,118 euros per kWh	0,109 euros per kWh
From 01.01.2022 to 31.12.2022	0,115 euros per kWh	0,105 euros per kWh
From 01.01.2023 to 31.12.2024	0,110 euros per kWh	0,101 euros per kWh
From 01.01.2025 to 31.12.2029	0,107 euros per kWh	0,097 euros per kWh

Currently, a system of "green" auctions has been launched and is functioning in Ukraine. Their main task is to replace "green" tariffs and ensure competitive pricing for new alternative energy projects. According to the adjustments adopted in April 2019, photovoltaic stations with an installed capacity of more than 1 MW and wind stations - more than 5 MW, will be required to win the auction for the allocation of state support quotas. The Cabinet of Ministers will determine the total annual volume of these quotas (installed capacity of the power plant) [14].

In August 2020, key amendments to the legislation of Ukraine on support for renewable energy (RES Law) came into force. The RES Law implements the Memorandum of Understanding signed on June 10, 2020 between the government and renewable energy associations to stabilize the electricity market. Below is an overview of the provisions of the RES Act.

This document is a long-awaited result of a long mediation process. The Government expects that the signing of the Memorandum will avoid lawsuits against Ukraine for investment arbitration and preserve the country's investment attractiveness. The memorandum establishes the commitments of the government and renewable energy producers.

This document is not an act of legislation, but rather a roadmap for future regulatory changes. The government submitted to parliament a draft law on the implementation of the Memorandum and facilitated its adoption in 2020 (the "Law on Arrangements"). It is the parliament that determines the final changes to the legislation on RES.

The memorandum is open for accession of all RES producers. They can decide voluntarily whether to sign this document. RES producers who do not meet the conditions of the Memorandum may refuse to join it. However, the legal consequences of refusing to sign at the moment are ambiguous.

3.2.1 Reduction of the "green" tariff

The main element of the RES Law is the reduction of the "green" tariff. The decrease applies to solar power plants and wind power plants (WPPs), which are already in operation and are under construction. The degree of reduction of the "green" tariff depends on the type of technology (sun or wind), production capacity and date of commissioning. The RES Law does not extend green gas tariff contracts beyond the current deadline, January 1, 2030 [15].

Table 3.2 – Put into operation before July 1, 2015.

WPP	without reduction
SPP	price cap (22 eurocents per kW)

Table 3.3 – Put into operation after July 1, 2015.

WPP	7.5%
SPP below 1 MW	7.5%
SPP 1 MW and above	15%

Table 3.4 – Put into operation after January 1, 2020.

WPP	2.5% [1]
SPP below 1 MW	2.5%
SPP 1-75 MW	
– put into operation by November 1, 2020	2.5%
– put into operation during November 1, 2020 - March 31, 2021	30%
– put into operation after March 31, 2021	60%
SPP 75 MW and above	
– put into operation by November 1, 2020	2.5%
– put into operation after November 1, 2020	60%

The National Commission for State Regulation of Energy and Utilities reduced the rates of the "green" tariff for all existing RES projects on August 1, 2020. The revised green tariff rates apply from the same date [15].

3.2.2 The final date for the commissioning of the project (cut-off date)

The RES Law does not set a deadline for the commissioning of RES projects. As before, to obtain a "green" tariff, SPP must be put into operation within two years after the date of the pre-PPA, and WPP - within three years. Instead, the RES Act restricts new solar generation by radically reducing the "green" tariff. As mentioned above, SPP with a capacity of more than 1 MW, put into operation after November 1, 2020, will be reduced by 30% to 60%.

The RES Law introduces the so-called "stabilization" provision, according to which "green" tariff rates will not be reduced in the future. RES projects will be protected from changes in Ukrainian legislation that may occur after the entry into force of the Law on RES. However, the "stabilization" provision does not apply to changes in legislation in the areas of defense, national security, public order, and environmental protection [15].

It is currently unclear whether the "stabilization" position will protect foreign investors from tax changes The Law of Ukraine “On Alternative Energy Sources” states that the “stabilization” provision applies to tax legislation, as the Law of Ukraine “On the Foreign Investment Regime” specifies taxation as an exception to this provision. This uncertainty is due to the last-minute amendment to the RES Law.

3.2.3 Allowance for the local component

The Law on RES increases the allowance for RES of projects put into operation between July 1, 2015 and December 31, 2024, for the use of Ukrainian-made equipment in the construction of the power plant. The allowance is paid in addition to the "green" tariff and is calculated by multiplying the rate of the "green" tariff by a factor, as shown below. The NCSREU sets the allowance on the basis of the provided calculations and documents [15].

Table 3.5 – Allowances for the local component as a percentage.

Allowances for the local component	Coefficient
30-50%	5%
50-70%	10%
> 70%	20%

3.2.4 Financial responsibility for imbalances

According to the RES Law, the financial responsibility for imbalances will not change only for RES projects with a capacity of less than 1 MW. For them, the transition period for the gradual introduction of liability for imbalances continues. Starting in 2021, these RES projects will pay only 10% of the costs of settling imbalances. This share will increase by 10% annually until 2030. Instead, for RES projects over 1 MW, the share of financial responsibility will be 50% in 2021 and 100% from 2022 [15].

In addition, the RES Act halves the permissible errors in forecasting electricity supply for all RES projects. Under the previous regulation, the liability for imbalances did not apply in case of deviation of the actual hourly volumes of electricity supply from the hourly supply schedule by less than 10% for SPPs and 20% for WPPs. The RES Law reduces the tolerances to 5% for SPPs and 10% for WPPs.

3.2.5 Increasing the liquidity of the Guaranteed Buyer

The RES Law introduces several measures to ensure the repayment of growing green tariff arrears and to ensure timely payments in the future.

First, the transmission system operator, NEC Ukrenergo (TSO), must transfer 35% of the income received from the allocation of interstate capacity to the Guaranteed Buyer to repay the debt. Second, the government must submit a bill by November 1, 2020 on the issuance of domestic government bonds with a maturity of 5 years for the same purpose [15].

Third, the government may provide for the financial support of the Guaranteed Buyer to pay a "green" tariff of at least 20% of the projected electricity production from RES.

Fourth, the Guaranteed Buyer may sell electricity under bilateral agreements. Also, the TSO tariff for electricity transmission should include financing provided by the TSO to the Guaranteed Buyer to ensure payments under the "green" tariff [15].

3.2.6 Compensation for unproduced electricity

Starting in 2021, the TSO must pay RES for electricity compensation not generated as a result of the implementation of the TSO load reduction commands to ensure reliable network operation. These costs will be covered by the TSO tariff for electricity transmission. By September 1, 2020, the NCSREU will introduce a mechanism for compensation for future and past reductions in production [15].

3.2.7 "Green" auctions

RES projects that do not receive a "green" tariff will obviously be interested in participating in "green" auctions. As a lot at these auctions will be offered the possibility of guaranteed sale of electricity to the Guaranteed Buyer at the auction price for 20 years. The RES Law also amends the legislation on auctions.

First, it sets price caps, on the maximum auction price:

Table 3.6 – Maximum auction prices.

Type of technology	Price caps
WPP and SPP	9 eurocents per kWh - during 2020-2024. 8 eurocents per kW / h - in the following periods
Other RES projects	12 eurocents per kWh

Second, wind farms with a capacity of more than 5 MW with three turbines are now also required to participate in "green" auctions, as they were previously exempted from this obligation.

Third, the government must approve an annual support quota (the amount of capacity offered at green auctions) for the next year and indicative annual quota forecasts for the next four years.

Fourth, the government may designate certain regions of Ukraine (for example, regions with electricity shortages) to build new RES projects within the annual support quota [15].

3.3 Basic description of NPV, IRR

The most important criteria for project performance are payback period, profit margin, net present value, internal rate of return. Only the project whose indicators turned out to be the most attractive receives funding. How to evaluate the effectiveness of the investment project? The most important indicators of such analysis are the values of NPV and IRR. NPV is the balance of all operating and investment cash flows that considers costs. A project is considered effective if it not only covers internal costs but also generates income that is not lower than the discount rate. The following formula is used to calculate the net present value:

$$NPV = \sum_{i=0}^{n} \frac{NCF_i}{(1+k)^i}$$

where: NCF_i - net cash flow at the appropriate time; n is the number of years; k - the discount rate, the most important element of the formula. Any error in calculating NPV may reduce the effectiveness of investments.

In addition, the definition of NPV is very important because it allows you to consider the entire life cycle of the project and determine its profitability.

IRR is the amount of the discount rate at which the net present value is zero. Specifies the maximum possible annual income used in the calculation to maximize the attractiveness of the project. A project is effective when the return on capital expected by the investor is less than the IRR. To determine the IRR, you can use the formula NPV, equating it to zero:

$$0 = \sum_{i=0}^{n} \frac{NCF_i}{(1 + IRR)^i}$$

The solution I can deduct from the equation depends on the change in NCF_i. However, changes in value throughout the project period of the money do not need to be considered [16].

3.4 Stages of system selection and calculation

The solar photovoltaic system includes various components. The main components of the solar photovoltaic system are the solar charge controller, inverter, battery, auxiliary energy sources and loads (devices).

PV-module – converts sunlight into electricity (DC).

Charge controller – regulates the voltage and current coming from the PV panels going to the battery and prevents recharging the batteries and extends their life.

Inverter – converts input DC current from PV panels (or wind turbine) into AC for consumer use.

Rechargeable battery (battery) – saves energy for future use (in the absence of network or unsatisfactory quality).

Loads – electrical devices connected to a solar photovoltaic system.

Auxiliary energy sources – diesel generator or other renewable energy sources.

The calculation of a solar power plant can be divided into several main stages.

3.4.1 Choice of photovoltaic module technology

Before starting to complete the photovoltaic (PV) system, it is necessary to choose the category of panels. Currently, there are two main categories of solar panel production on the market: monocrystalline solar panels (mono) and polycrystalline solar panels (poly).

To make solar cells for modules, silicon is formed into bars and cut into waffles. Photomodules of mono technology have better efficiency and more complex manufacturing technology. The name "mono" means that the silicon used consists of one component. Electrons that generate the flow of electricity have more room to move. As a result, "monocrystal" panels are more efficient than their polycrystalline counterparts.

According to this information, I chose "monocrystal" JA SOLAR panels with multilayer PERC cells and a semi-cell configuration of the modules.

Combined with multi-busbar PERC cells, the module's half-cell configuration offers the benefits of higher power output, better temperature-dependent characteristics, reduced shading effect on energy quality and quantity, lower heating risk, and increased load resistance.

So, the selected module is JA Solar 340W 5BB Half-Cell Module, JAM60S10 320-340/MR series [Annex A].

Voltage and amperage are important characteristics for any solar panel. In the following figure I illustrate the dependence of these indicators on the level of insolation.

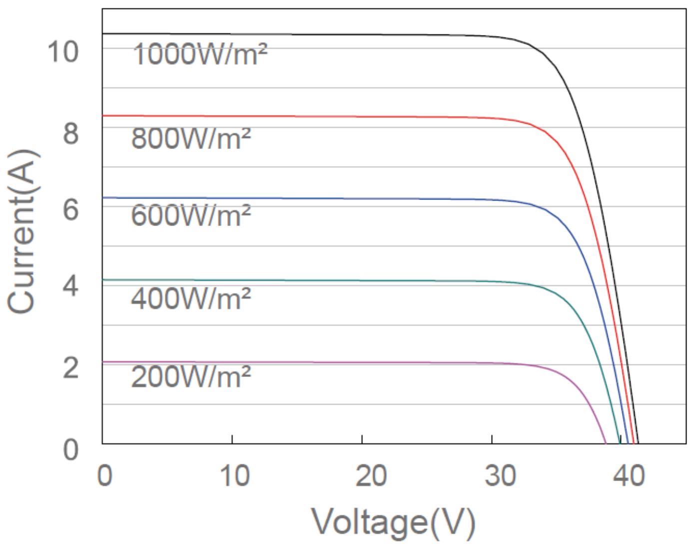


Fig 3.1 – Curve of current and voltage dependence on insolation of JA Solar JAM60S10 320-340/MR, 340 W [Annex A].

3.4.2 Amount of PV modules needed for 1.19 MW

The most important thing in calculating the number of modules is the required SPP power. Manufacturers of inverters report that for efficient operation of the station, it can be overloaded by 20-30%, so for SPP with a capacity of 1.19 MW, so I chose the number of panels to provide power, for example, overloaded by 20%.

In my case the required SPP power P_r = 1,19MW. According to this information I found a solution by dividing required SPP power into power of one PV module p_m = 340W:

$$N = \frac{P_r}{p_m} = \frac{1000000 + 200000}{340} = 3529,4\text{pcs.}$$

Since the orientation of the solar panels to the south, I can conclude that the volume of annual insolation will be 100% (and accordingly k_p = 1), according to (Fig. 3.2).

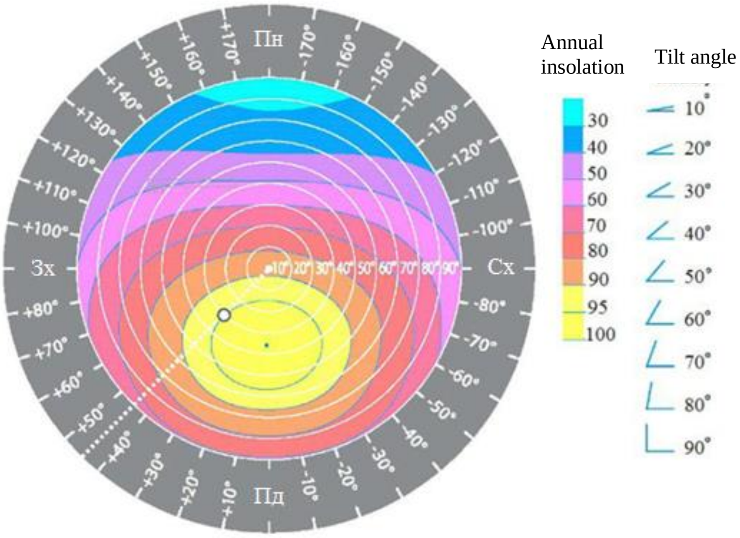


Fig. 3.2 – Influence of tilt angle orientation on relative volumes of solar energy utilization [17].

For correct operation of the station it is necessary to distribute the modules correctly. Each selected inverter has a certain number of MPPTs (maximum power point tracker) that need to be loaded evenly [Annex B].

3.4.3 Inverter selection

Solar photovoltaic system (or solar power plant) is one of the systems that uses renewable energy sources - thanks to solar panels is the conversion of sunlight into electricity. The produced electricity will probably be:

- to accumulate - in accumulators (batteries);
- use directly by the consumer;
- return to the public network;
- combine in combination with one or more other energy sources (generator, etc.).

The solar photovoltaic system is a very reliable and clean source of electricity. There are many nuances to consider when choosing a hybrid inverter or a hybrid system with batteries.

The initial cost of a hybrid inverter is quite high, but this is offset by the possibility of more flexible use of your generated energy, instead of buying energy from the grid when solar panels do not generate electricity. Hybrid inverters have proven their reliability when working in different networks.

Inverters are an integral part of solar photovoltaic systems. Solar panels generate electricity in the form of direct current (DC). However, most of our power grid is alternating current (AC). Therefore, the power from DC sources, such as solar panels, must be converted (inverted) into alternating current.

The inverter is the most technically complex part of a solar photovoltaic plant. It consists of a number of components that convert DC to AC. The controller chips are programmed to maximize the output power from the PV panels.

Such equipment that especially needs a pure sine wave. Different types of inverters have ways to optimize performance. Inverters allow each panel to operate independently, which eliminates the effect of partial shading. Fronius - have built-in monitoring, etc. [18].

Inverters can be divided into three types: stand-alone, network and hybrid.

Network. Synchronized with the grid and mainly used to sell electricity to the grid at a "green tariff".

Fig. 3.3 – Mains inverter [18].

Stand-alone. Under autonomous power supply from solar batteries understand complete replacement of network power supply on autonomous. Such a scheme is relevant for the power supply of facilities remote from the main power lines, in hard-to-reach places or places where the laying of such lines is impossible or economically unprofitable.

When installing such a system, it is important to consider the voltage and capacity of the battery to ensure compatibility of all components and the required autonomous duration.

There should also be enough solar energy to start the inverter and charge the batteries.

Fig. 3.4 – Stand-alone inverter [18].

Hybrid. Combine the two previous types of inverters. They are connected to the network. Combine the two previous types of inverters. They are connected to the network. However, during periods of excess power generation, the additional power generated may be stored in the battery rather than exported to the grid (after the battery is fully charged). This can be especially useful in areas where the network is unstable, as the stored energy can provide power during shutdowns or inappropriate network parameters. The hybrid inverter is not equipped with a battery and solar panels - they are purchased separately [18].

Fig. 3.5 – Hybrid inverter [18].

The choice of the inverter is carried out based on the rated power of the PVPS and checked under the conditions of idling and short circuit. Modern inverters are equipped with devices for tracking the maximum power point tracker.

For this task I chose a hybrid system that includes three voltage inverters Victron Energy Quattro 48/15000/200-100/100, 1 phase 12 kW of power each and 6 charge controllers Smart Solar MPPT 150/100-MC4, 5.8 kW each. Detailed technical characteristics of inverters and controllers are presented in Annex C. 18 panels are connected to one MPPT charge controller.

A total of 108 panels are connected to one hybrid system, giving a total of 36.72 kW of power. Thirty-three such systems must be used. This means:

$$P_r = 36{,}72 \cdot 33 = 1{,}2118 \text{ MW}.$$

The next step is to choose the optimal installation angle of the photomodule relative to my location.

For calculation of the distances between rows of modules I found optimal angle of inclination for PV modules.

By geographical location (in my case, the Kyiv city, orientation to the south), the angle of inclination of the sun in azimuth relative to the earth in summer is 63 degrees and in winter 16 degrees.

So, for optimal operation of the station it is necessary to choose the average value of this angle:

$$A = \frac{63 + 16}{2} = 39{,}5°.$$

3.4.4 Distances between rows of modules/avoid shadow

In my case, I used two constructions with two rows of modules. First 12 constructions will consist of 119 modules for each row, second 3 constructions will consist of 118 modules for each row. There is a total of 15 such constructions.

Fig. 3.6 – Model of the construction location with two rows of modules [19].

Because of grass and snow, minimum modules height above the earth is 0.5m. Length for two modules is (based on passport data of modules):

$$L = 1689 + 1689 = 3378 \text{ mm.}$$

Row heights:

*H = construction height (h) +sin (panel angle) * panel length (L).*

Width of the row:

*W = cos (panel angle) * panel length (L)* = 2627 mm.

Calculation results are shown on Figure 3.7.

Considering the winter angle of the sun (16°), determining the length of the shadow, and hence the projection on the ground, I can conclude that the distance between the rows is 7418 mm.

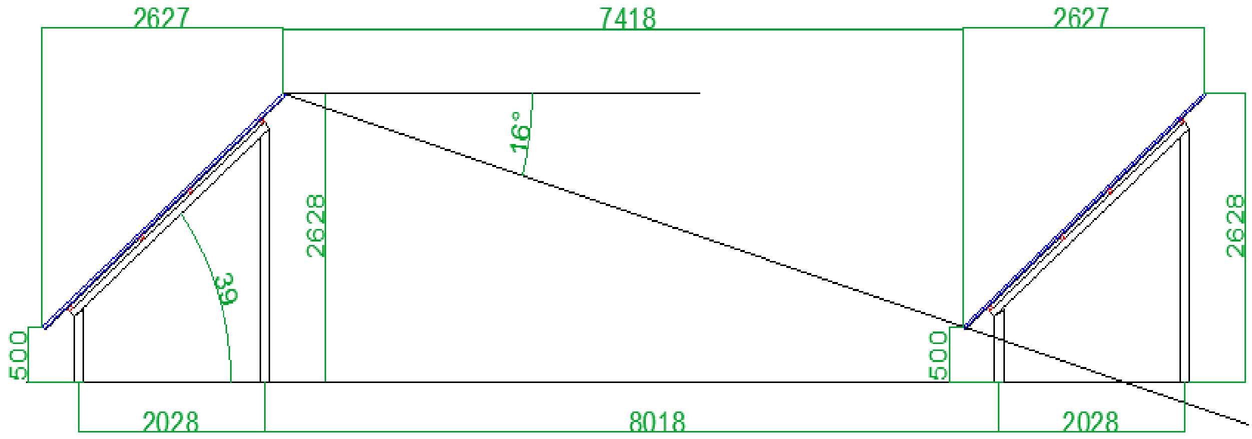


Figure 3.7 – Distances between rows of modules/avoid shadow.

3.4.5 Calculation of the area needed for 1,19 MW plant

To calculate the total area of a solar station with a capacity of 1.19 MW, it is necessary to determine the length of one construction. Length (*b*):

$$b = 118 \cdot 0{,}996 + 119 \cdot 0{,}024 = 120{,}39\ m.$$

According to the width of row (*W*), numbers of rows (*C*) and the sum distance between the rows (*D*) I can calculate *a*:

$$a = W \cdot 15 + D \cdot 14 = 2{,}627 \cdot 15 + 7{,}418 \cdot 14 = 138{,}3\ m.$$

According to the width (*a*) and length (*b*) I can calculate total area (A_t).

Total area equal: *a*b*

$$A_t = a \cdot b = 138{,}3 \cdot 120{,}39 = 16{,}650\ m^2 = 1{,}665 \text{ ha}.$$

3.4.6 Determining the capacity of batteries

The type of battery recommended for use in SPP is a battery with a deep discharge cycle. A deep cycle battery is specifically designed to discharge to a low residual energy level and recharge quickly or to cycle and discharge day after day for many years. The battery must be large enough (a multi-battery unit) to store enough energy to operate the devices at night and on cloudy days. To find out the battery capacity, calculate the following:

In this case, it should correspond to one third of the total capacity of the SPP, the rest of the electricity will be sold to the grid. Under the worst operating conditions, SPP will generate 1.2 MWh of electricity. That is why I am counting on this amount of electricity generated. Divide the total watt-hour/day by 0.85 to compensate for battery loss.

$$1200000/0{,}85 = 1411764{,}7\ \mathrm{Wh/day}$$

I divide the answer obtained in the previous paragraph by 0.8 - to take into account the depth of the discharge (DOD 80%).

$$1411764{,}7/\ 0{,}8 = 1764705{,}9\ \mathrm{Wh/day}$$

I divide the result by the rated voltage of the battery (in this case 48V).

$$1764705{,}9/48 = 36764{,}71\ \mathrm{Ah/day}$$

Thus, the batteries built into the hybrid system have sufficient capacity to provide the required backup conditions.

The energy produced by the power plant should charge the batteries and, if possible, for example in the summer, sell to the grid.

To ensure a reliable supply of power to consumers of category I, it is necessary to use an ATS device, which at the signal of the voltage relay, in the absence of mains voltage, will switch the power supply from the inverter via a modular contactor.

In the normal mode of supply, energy is supplied through the contactor to the main lighting panel, emergency lighting and fire and burglar alarms.

3.5 Checking the system for compliance

So, I tested the selected inverter and solar panels under the following conditions (the results of this test are consistent with all 33 systems):

– parallel strings must have the same number of panels;

– the number of panels in the string should not exceed the maximum allowable number N_{max}:

$$N_{\text{panels in the string}} < N_{max}$$

$$3 < 3{,}61$$

The short-circuit current per MPPT must not exceed the permissible value:

$$I_{\text{sc panels}} \cdot N_{\text{string}} < I_{\text{add}}$$

$$10{,}46 \cdot 6 = 62{,}76\text{A} < 100\text{A}$$

where $I_{\text{sc panel}}$ – panel short circuit current; I_{add} – permissible current per MPPT according to its passport data; N_{string} - the number of string connected in parallel with the panels to one controller.

– the voltage per MPPT must not exceed the permissible value:

$$U_{\text{panel}} \cdot N_{\text{panel in the string}} < U_{max}$$

$$41{,}55 \cdot 3 = 124{,}65\text{B} < 150\text{B}$$

where U_{max}– the maximum operating voltage of the controller according to its passport data; U_{panel} - operating voltage of the panel according to passport data.

The operating parameters of the selected charge controller set the maximum system voltage U_{max}, and the no-load voltage of the photovoltaic module 41.55 V, so you can connect in series no more than N_{max} number of solar panels:

$$N_{max} = \frac{U_{max}}{U_{xx\ \text{пан}}} = \frac{150}{41{,}55} = 3{,}61\ panel,$$

however, this system requires only 3 panels per line and 6 such lines.

3.6 Determining the load center of the design object

Since the station is located on the territory of the CHP, it is possible to create several load centers, which will help reduce losses in the cable during the transmission of electricity. Eleven such centers will need to be made, each of which will house 3 hybrid systems.

3.7 Analysis of the designed system possibilities

The location of the system with a south orientation, allows to get the most efficient version of the station. Since a large area of ash drainage can be used to build SPP, it is possible to avoid any impact of the shadow on the operation of the station. Placing structures at the required distance from each other allows you increase the efficiency of 7-10%.

Due to the fact that the photovoltaic modules are not located on the roof and do not have any contact with the roof surface, their operating temperature will be much lower.

Equally important is the fact that the photovoltaic modules are located at a relatively low height, which allows them to be serviced during operation.

When placing the station on the territory of the CHP, the need for additional protection of the station and the fence of the territory disappears.

Due to the fact that the system includes rechargeable batteries, it is possible to store electricity, and therefore use it only for the necessary period.

There may be several such options:

1. The accumulated electricity can be used in the period when it is necessary to regulate the generated electricity by the thermal power plant. This will help provide additional backup and prevent unplanned shutdowns or downsizing of reactors.
2. Also, electricity generated by SPP can be sold in periods when electricity from CHP is more expensive.
3. The main part of electricity from SPP will be sold to the grid without the use of additional power distribution devices and substations, as it is possible to use the existing network. This significantly reduces the cost of SPP.

3.8 Selection of the system power elements

An important value when choosing the power of transformers is the correct accounting of their load capacity. Under the load capacity of the transformer means a set of allowable loads, systematic and emergency overloads based on the thermal wear of the transformer insulation. If do not take into account the load capacity of transformers, it can be unreasonably overestimate the choice of their rated power, which is not economically feasible [20].

At the vast majority of substations, the load of transformers changes and for a long time remains below nominal. A significant part of the transformers is selected taking into account the post-emergency mode, and therefore they normally remain unloaded for a long time. In addition, power transformers are designed to operate at a permissible ambient temperature of + 40^{o}C. In fact, they work under normal conditions at ambient temperatures up to 20 ... 30^{o}C. Therefore, the power transformer at a certain time can be overloaded taking into account the above circumstances without any damage to its service life (20-25 years).

Based on studies of different modes of operation of transformers developed GOST 14209, which regulates the allowable systematic loads and emergency overloads of general-purpose power oil transformers with a capacity of up to 100 mVA, including cooling M, D, DC and C, taking into account the cooling temperature[20].

To determine the systematic loads and emergency overloads in accordance with GOST 14209, it is also necessary to know the initial load preceding the overload and the duration of the overload. These data are determined by the actual initial load schedule (full power or current), converted from a thermally equivalent to a rectangular two- or multi-stage schedule.

Due to the need to have a real initial load schedule, the calculation of allowable loads and overloads in accordance with can be performed for existing substations to verify the admissibility of the existing load schedule, as well as to determine possible options for daily schedules with maximum values of load factors in the previous mode, overload and in overload mode[20].

At the design stage of substations, you can use standard load schedules or in accordance with the recommendations also proposed in GOST 14209 to choose the power of transformers under the conditions of emergency overloads [20].

Then for substations where emergency overloading of transformers is possible (two-transformer, single-transformer with backup connections on the secondary side), if the calculated load of the object S_{p} and the coefficient of allowable emergency overload K_{L} is known. the rated power of the transformer is defined as:

$$S_{\text{n.т.}} = S_{\text{p}} / K_{\text{L}}$$

It should also be noted that the load of the transformer on top of its rated power is allowed only with a working and fully turned on the cooling system of the transformer.

As for the typical schedules, they are currently designed for a limited number of load nodes [20].

Since the choice of the number and capacity of transformers, especially consumer substations 6-10/0.4-0.23 kV, is often determined mainly by economic factors, it is important to take into account the compensation of reactive power in the consumer's electrical networks.

The choice of the number of power transformers is determined together with the choice of static capacitor banks.

Since the plant is an economic entity and is not part of the enterprise, the condition for zero consumption of reactive power is at this level of the network, and the reactive power is regulated in accordance with section 2.6. Therefore, the substation is calculated without taking into account the reactive power but taking into account the active power and the possibility of technical accounting [20].

For this SPP when choosing a transformer, I used the data of calculations on the low voltage side. Since the station is designed to sell residual electricity to the grid, it is advisable to classify it as reliability category I and install a two-transformer substation. The choice of transformer must be made taking into account the load factor. For two-transformer substation with a predominant load of category I, the recommended load factor is:

$$К_L = 0{,}65,$$

from here I can determine the rated power of the transformer:

$$S_{n.\text{т}} = \frac{1211{,}8}{0{,}65} = 1864{,}3 \text{ кВА}$$

Based on the calculations, it is advisable to choose a two-transformer substation with a capacity of 1000 kVA transformer voltage of 10 kV with a cabinet of street lighting with cable entries HV type 2PTSUN-1000/10/0,4-ShK-U1 with circuit breakers on the outgoing lines [Annex D]. PTSUN (packaged transformer substation for urban electrical networks) are delivered in a metal cabin of high factory readiness (2PTSUN - in two cabins), with the power transformer mounted in it, HVS cabinet (high voltage switchgear), street lighting cabinet.

In the HVD (high voltage device) cabinet, AC load-break cutout with manual drive and spring-loaded drive are installed. Fuse switches or circuit breakers are installed in the HVS compartment, as well as general electricity metering and electricity metering for street lighting (if necessary). In the HVS compartment light panel-94 panels with ATS on the 0.4 kV side are installed. The length of the cabin is 4540 mm [Annex D].

MPTSUN with RM6 units manufactured by Schneider Electric with insulation installed in HVD cabinets are also supplied. In HVS cabinets the Masterpact M20N1 switch (manufactured by Schneider Electric) for rated current up to 2000 A with regulation of current on disconnection is established on input, on outgoing lines Multivert safety switches for rated current up to 630 A, manufactured by Schneider Electric or others firms. Option of execution 2 MPTSUN in one cabin (input air or cable).

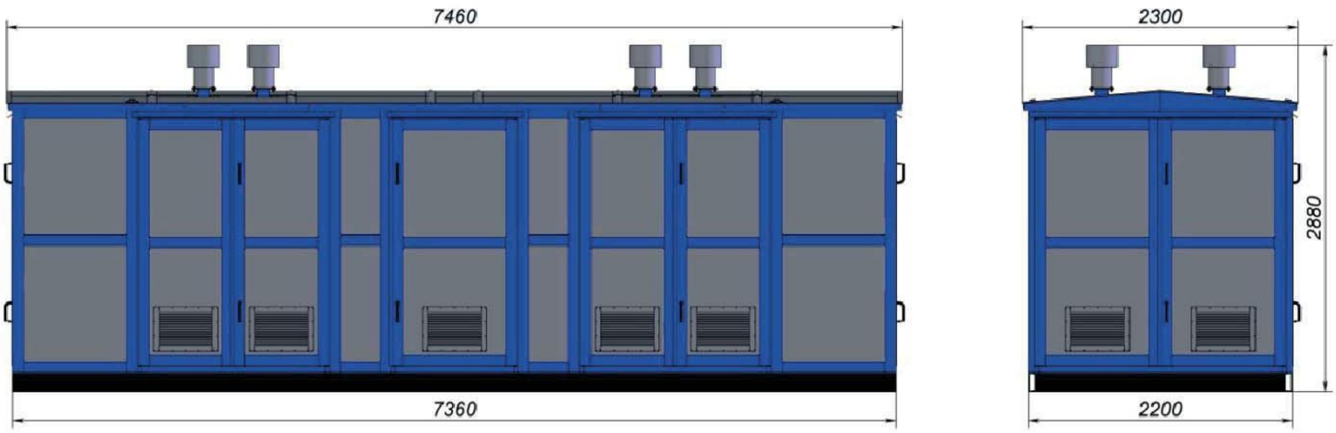


Fig. 3.8 – Execution options 2 MPTSUN [Annex D].

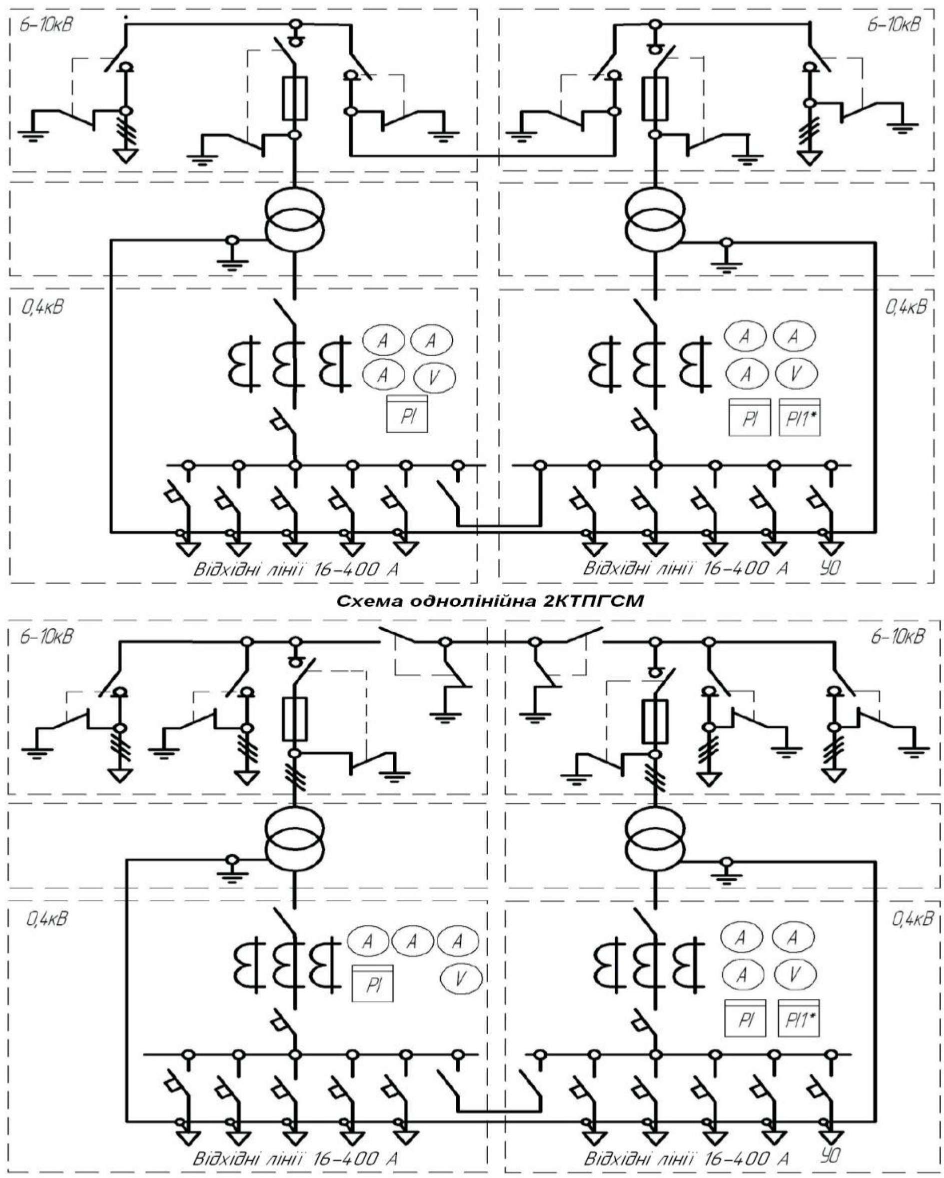


Fig. 3.9 – Single-line electrical circuits 2 MPTSUN [Annex D].

With regard to the switching equipment of the solar station itself, each output link of the system must be protected against short-circuit currents, which are performed by circuit breakers or fuses. Each inverter must be protected by a surge protection device.

Fuses and their fusible inserts are selected under three conditions:

$$I_{н.з.} \geq I_p;\ I_в \geq I_p;\ I_в \geq I_n / K_{с.п},$$

where, $I_{н.з.}$, $I_в$ - rated currents of fuse and fuse-link; $K_{С.П.}$ – start-up complexity factor, I_n – starting current.

Circuit breakers are selected under the following conditions:

- rated thermal current I_T, electromagnetic I_e and electromagnetic $I_к$ releases are selected by the rated current:

$$I_T \geq I_P;\ I_e \geq I_p;\ I_к \geq I_p;$$

- the operating current of the electromagnetic $I_{сп.е}$ or the combined $I_{сп.к}$ release is checked for peak current:

$$I_{сп.е} \geq 1,25 I_п;\ I_{сп.к} \geq 1,25 I_п;$$

- the operating current of the circuit breaker with adjustable inversely dependent current characteristic:

$$I_{сп.р} \leq 1,25 I_р.$$

The choice of relay protection and automation devices was made at the stage of installation of switchgear. As 2 MPTSUN is used for connection of SPP to a network installation of new elements is not required.

3.9 Organization of accounting and determination of economic characteristics

To ensure control and metering of electricity, a point of commercial metering of electricity is established. The item includes a special device for monitoring and controlling the operation of the Color Control GX system [Annex E]. Color Control provides intuitive control and monitoring for all Victron power systems.

Due to the use of hybrid systems on the low voltage side, a bidirectional electricity meter is included, which will provide metering of energy coming from the SPP.

I used a three-phase bidirectional meter ACE6000 5-100A [Annex F]. The characteristics of this item are given in Table 3.7.

Table 3.7 – Characteristics of ACE6000 5-100A [Annex F].

Rated voltage, kV	6 (10)
Maximum operating voltage, kV	7,2 (12)
Rated frequency, Hz	50
Rated current of the main circuit, A	50-600
Rated current of secondary circuits, A	5
Rated voltage of secondary circuits, kV 100,	100
Short circuit current	32
Accuracy class of the meter 0.2	0,2
Level of protection of GOST 14254 IP54	IP54
Climatic performance and accommodation category U1	У1

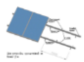
3.10 Formation of the equipment price and the SPP total cost

To analyze the challenges of installing a solar station on the ground structure, the impact of these aspects on the cost of the station and evaluate the effectiveness of the investment project. Determine the value of profitability and payback of a solar power plant using NPV and IRR functions.

For more accurate and reliable calculations, data on electricity production were taken from a special medium called HelioScope [19]. This program allows to assess the current performance of SPP and even make a forecast for years to come.

For this station, the prices of design and estimate and commissioning works for the construction of SPP with 1,19 MW capacity are taken according to the website of the company dealing with solar power plants in Ukraine [21] and shown in Table 3.8.

Table 3.8 – The prices of design and estimate and commissioning works.

№	Name			Units	Price $ **	Solar power plant 1MW (PV 1,2118 MW) Productivity per year: 1 229 MWh	
		Equipment	Producer			Quantity	The total cost, $
1		PV module JA Solar JAM60S10-340W MBB, Mono (PERC) Halfcell,	China	pcs.	106,00	3564	377 784,00
2		Charge controller Victron Energy SmartSolar MPPT 150/100-MC4	Netherlands	pcs.	1 100,00	198	217 800,00
3		Invertor Victron Energy MultiPlus 48/15000/200-100/100 (15 кVA/12 кW, 1 fase)	Netherlands	pcs.	6 200,00	99	613 800,00
4		Web interface Victron Venus GX	Netherlands	pcs.	340,00	33	11 220,00
5		Battery Pylontech LV 70.4 (70,4 kWh, 48 V) Power supply in the battery - 56 kWh	China	pcs.	45 000,00	32	1 440 000,00
6		Fastening	Ukraine	pcs.	23,00	3564	81 972,00
7		PV connectors LAPP EPIC SOLAR MC4***	Germany	2 pcs.	2,00	396	792,00
8		PV cabel IBC SOLAR FlexiSun 6мм² black/red***	Germany	m.	1,50	9900	14 850,00
9		Automation of current protection of DC: switches-disconnectors + automatic switch. Switches, input automatic, metal two-section board	Germany	pack	240,00	33	7 920,00
10		AC and DC surge protection Saltek: Surge protection devices for alternating current - type 1 + 2, grounding. Without external lightning protection	Germany	pack	190,00	33	6 270,00
					All, $ **		**2 772 408,00**

Services:

№	Descript.	Labor	Performer		Price, $ **	Quantity	The total cost, $
11		Installation, electrical work, commissioning, engineering	…	service	2 100,00	33	69 300,00
12		Mounting kit: metal sleeve, UV-resistant corrugation, AC cable, ground cable, insulating materials, tray	…	pack	150,00	33	4 950,00
					Total price $ **:		**2 846 658,00**

Table 3.9.1 and Table 3.9.2 describe the operation of the 1.19 MW station in the period from the beginning of its construction to 11 years of operation (2018 - 2029). This time range is taken to show the change in the tariff (decreased by 25% in 2020) and the impact of this change on the profitability of the station. According to the amendments of the National Commission on the formation of the "green" tariff, the interest rate for a fee per kilowatt of electricity decreased by 2.5% (Table 3.9.1, Table 3.9.2). Also, based on the efficiency of photomodules, it is necessary to consider the criterion of their aging (degradation), which for photomodules JA Solar JAM60S10, according to the technical characteristics is approximately 0.8% per year. The performance of the station with considering the degradation is also shown in Table 3.9.1 and Table 3.9.2.

Table 3.9.1 – The operation of the 1 MW SPP (2018-2023).

	0	1	2	3	4	5
Month	2018	Production 2019(kWh)	Production 2020(kWh)	Production 2021(kWh)	Production 2022(kWh)	Production 2023(kWh)
January		33057,0	33065,8	33091,3	33065,8	33062,9
February		50039,6	50045,6	50093,2	50048,1	50042,3
March		100916,6	100939,8	101005,5	100939,4	100936,1
April		135480,3	135494,9	135584,3	135501,5	135491,9
May		175450,1	175462,0	175587,9	175468,5	175458,5
June		171628,5	171653,7	171746,3	171648,5	171631,2
July		173477,5	173494,3	173595,2	173486,5	173484,1
August		158480,0	158496,6	158606,9	158499,7	158490,4
September		112030,1	112045,1	112127,0	112054,0	112037,4
October		73568,2	73580,9	73630,2	73585,7	73575,3
November		33190,6	33194,9	33223,4	33197,5	33192,3
December		21228,4	21229,6	21252,8	21230,9	21228,6
∑, Year		1238546,9	1238703,2	1239544,0	1238726,1	1238631,0
Degradation%	0,00	0,80	1,60	2,40	3,20	4,00
With degradation		1228638,5	1218883,9	1209794,9	1199086,9	1189085,8

Table 3.9.2 – The operation of the 1 MW SPP (2024-2029).

	6	7	8	9	10	11
Month	Production 2024(kWh)	Production 2025(kWh)	Production 2026(kWh)	Production 2027(kWh)	Production 2028(kWh)	Production 2029(kWh)
January	33062,3	33063,6	33067,8	33065,2	33060,7	33063,1
February	50043,0	50046,3	50051,3	50044,8	50038,8	50041,7
March	100925,0	100934,9	100938,2	100932,8	100902,2	100919,1
April	135492,3	135492,8	135486,7	135490,8	135473,6	135478,8
May	175455,5	175468,0	175485,4	175457,4	175452,0	175456,8
June	171637,4	171652,2	171644,9	171639,7	171636,2	171634,6
July	173481,0	173488,2	173493,1	173491,1	173471,1	173476,6
August	158482,5	158496,3	158508,7	158488,5	158479,3	158483,8
September	112049,1	112051,0	112040,5	112051,3	112044,2	112044,3
October	73578,8	73581,2	73583,8	73582,3	73575,7	73578,7
November	33193,6	33194,6	33195,2	33196,4	33194,0	33193,7
December	21225,4	21230,1	21227,8	21226,7	21224,4	21224,2
∑, Year	1238625,9	1238699,2	1238723,4	1238667,0	1238552,2	1238595,4
Degradation%	4,80	5,60	6,40	7,20	8,00	8,80
With degradation	1179171,9	1169332,0	1159445,1	1149483,0	1139468,0	1129599,0

3.11 Calculation (NPV, IRR)

To determine the profitability and payback of a solar power plant, I used the NPV and IRR functions.

The main components of these calculations are the number of periods (in my case n = 11 years), annual energy production, the cost of energy produced at the green rate (according to subsection 3.10), capital (CAPEX) and operating (OPEX) expenses for construction and maintenance of the station.

The annual energy production (P) is determined according to the calculations of the HelioScope application [19].

CAPEX is defined in accordance with and divided into two types, CAPEX of the first big contribution to construction and equipment:

$$C_{ex1} = \$2846658$$

(total price from Table 3.8), and overhaul costs every 5 years $C_{ex2} = \$20000$ (the cost of replacing or repairing decommissioned equipment and constructions, approximate prices according to Table 3.8). OPEX - $O_{ex} = \$2800$ is the average value on the Ukrainian market to pay workers for the maintenance of the station twice a month.

All calculation in this Section will be shown an example of first year electricity production. Rest of calculations shown in Table 3.10.

First of all, I need to summarize costs (C) for each year.

$$C_1 = \left(-C_{ex1}\right) + \left(-O_{ex}\right) = 0 + \left(-2800\right) = \$\left(-2800\right)$$

For other years (C) can include both of the additions or other capital expense.

Second important value is cash flow (Cf) that can be calculated by the formula:

$$Cf_1 = P \cdot t_{0.17} + C_1 = 1228638{,}5 \cdot 0{,}17 + (-2800) = \$206068{,}5$$

where $t_{0.17}$ – "green tariff" according to Section 2. In the same Section also described "green tariff" for the rest years. The tariff is converted into dollars.

To find revenue (R), I need to sum the cash flow from the current year with all previous:

$$R_1 = Cf_1 + Cf_0 = 206068{,}5 + (-2846658) = -\$2640589{,}5$$

Table 3.10.1 – The calculations results of cash flow and revenue for year 2018-2023.

∑, Year		1238546,9	1238703,2	1239544,0	1238726,1	1238631,0
Degradation%	0,00	0,80	1,60	2,40	3,20	4,00
With degradation		1228638,5	1218883,9	1209794,9	1199086,9	1189085,8
Costs	-2 846 658,00	-2 800,00	-2 800,00	-2 800,00	-2 800,00	-22 800,00
Cash flow	-2846658,0	206068,5	147427,4	146307,2	144987,5	123754,8
Revenue($)	-2846658,0	-2640589,5	-2493162,0	-2346854,8	-2201867,3	-2078112,5
Tariff($/kWh)	0	0,17	0,123	0,123	0,123	0,123
CAPEX	2 846 658,00					20000,0
OPEX		2800,0	2800,0	2800,0	2800,0	2800,0

Table 3.10.2 – The calculations results of cash flow and revenue for year 2024-2029.

∑, Year	1238625,9	1238699,2	1238723,4	1238667,0	1238552,2	1238595,4
Degradation%	4,80	5,60	6,40	7,20	8,00	8,80
With degradation	1179171,9	1169332,0	1159445,1	1149483,0	1139468,0	1129599,0
Costs	-2 800,00	-2 800,00	-2 800,00	-2 800,00	-22 800,00	-2 800,00
Cash flow	142532,9	141320,2	140101,6	138873,8	117639,4	136423,1
Revenue($)	-1935579,6	-1794259,4	-1654157,8	-1515284,0	-1397644,6	-1261221,5
Tariff($/kWh)	0,123	0,123	0,123	0,123	0,123	0,123
CAPEX	0	0	0	0	20000	0
OPEX	2800,0	2800,0	2800,0	2800,0	2800,0	2800,0

The next step of the calculation is determining of IRR and NPV.

To calculate IRR I used Excel, namely IRR function which includes cash flow of all SPP work period and in my case, it is equal -9.02%.

For net present value calculation, I used two ways in Excel. First one is kind of manual calculation which include Discount factor (*Df*), Discount cash flow (*DCf*) and summation of all cash flows (*Cf*).

All calculation in this Section will be shown an example of first year electricity production. Rest of calculations shown in Table 3.10.

To Discount factor calculate by the formula:

$$Df_1 = \frac{1}{\left(1+Dr\right)^{per1}} = \frac{1}{\left(1+4\%\right)^{1}} = 96\%$$

where *Dr* – discount rate which equal 4%, *per* – period of calculation.

Discount cash flow (*DCf*) can be calculated:

$$DCf_1 = Cf1 \cdot Df1 = 206068{,}5 \cdot 96\% = 198142{,}84$$

To calculate NPV I used NPV value from previous year and discount cash flow from current year. NPV_0 equal discount cash flow [7]:

$$NPV_1 = NPV_0 + DCf_1 = -2846658{,}0 + 198142{,}84 = -\$2648515{,}16$$

To calculate NPV by Excel in another way I used NPV function which include Cash flow and Discount rate from current period and all periods before without Cash flow from zero period plus Discount Cash flow from zero period. To calculate it for last period I used all periods without Cash flow from zero period plus Discount Cash flow from zero period [22].

All calculations of this part of project are shown in Table 3.11.

Table 3.11 – Calculation of IRR and NPV.

Discount rate	4%	IRR(%)	Discount factor	Discount CF	NPV($)
Period	Cash flow($)				
0	-$2 846 658,0	-9,02%	100%	-2 846 658,00	-$2 846 658,00
1	$206 068,5		96%	198 142,84	-$2 648 515,16
2	$147 427,4		92%	136 304,96	-$2 512 210,20
3	$146 307,2		89%	130 066,59	-$2 382 143,61
4	$144 987,5		85%	123 935,89	-$2 258 207,73
5	$123 754,8		82%	101 717,44	-$2 156 490,28
6	$142 532,9		79%	112 645,85	-$2 043 844,44
7	$141 320,2		76%	107 391,72	-$1 936 452,72
8	$140 101,6		73%	102 370,87	-$1 834 081,85
9	$138 873,8		70%	97 570,87	-$1 736 510,97
10	$117 639,4		68%	79 472,99	-$1 657 037,99
11	$136 423,1		65%	88 617,83	-$1 568 420,16

Based on previous calculations, the NPV can be plotted (Figure 3.10).

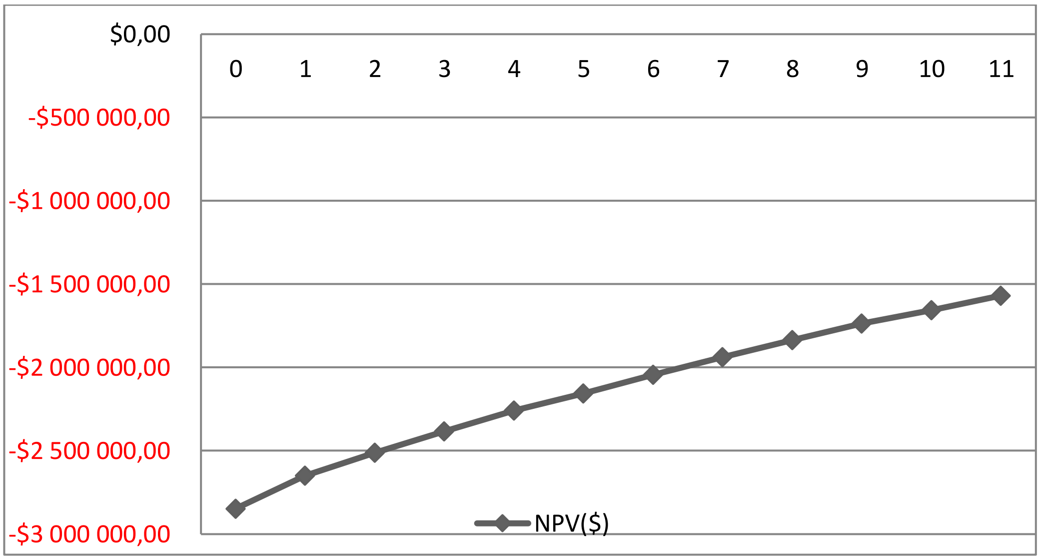


Fig. 3.10 – Dependence of NPV on time.

Based on IRR calculations, it can be concluded that the profitability of the station is -9.02% and in terms of payback, it is not attractive. However, the results of the study do not take into account the use of this system as a reserve and a way to regulate the operation of CHP provides financial benefits.

This system will provide an opportunity to participate in various market segments. Such segments may be the balancing market and the ancillary services market.

Instruments such as the balancing market and the market of ancillary services are provided for the purpose of providing sufficient volumes of electricity required for real-time balancing of electricity production and import, electricity consumption and export, settlement of system restrictions in the unified energy system of Ukraine, and financial settlement of electricity imbalances [22].

Conclusions to Section 3

The analysis of such station was carried out in connection with the rapid development of RES in Ukraine. The main stimulus for investment in the SPP was "green tariffs" and regulation of the energy market in Ukraine in general.

Based on the technical calculations in this project, I can conclude that with an increase in the total capacity of photomodules and an inverter load of 120%, the annual amount of energy produced can be significantly improved. Also, to increase the productivity of the station, it is important to find the optimal angle of inclination of the structures with panels and the distance between them to prevent shading. At the same time, the operation of the station during operation is affected by the degradation factor of the modules.

According to economic calculations, I determined that after eleven years of the station operation, I received a negative value of NPV, which amounted to approximately one million 568 thousand 420.16 dollars. As in the period after the study the "green" tariff will no longer apply in Ukraine, the issue of full payback is quite difficult. It is impossible to predict the profitability of the station for that period.

Based on IRR calculations, it can be concluded that the profitability of the station is -9.02% and in terms of payback, it is not attractive. However, it is important to understand that with the use of this system as a reserve and a way to regulate the operation of CHP, there is a financial benefit for the overall operation of the IPS (Integrated Power System) of Ukraine. This makes the station attractive to investors.

Therefore, this study may be useful for the further development of solar energy in Ukraine.

4 STARTUP PROJECT

4.1 Description of the project idea

The main requirements of the thermal power plant are uninterrupted production of electricity and heat in accordance with the demand and the projected load schedule. To ensure this requirement, units must be easy to maneuver their load without compromising the reliability of the equipment.

The next requirement is efficiency. The main cost of production is fuel, which is also harmful to the environment.

In line with global trends to reduce the price of electricity produced from renewable energy sources and the partial replacement of electricity produced at thermal power plants by electricity from renewable sources, there is a possibility of combining these two systems for mutual compensation. After all, the main disadvantage of, for example, solar energy is the inability to regulate its productivity, which in turn is easily managed by thermal power plants.

The idea of the project is to create a software module for monitoring the efficiency of the combination of thermal and solar power plants.

The module will analyze and provide the joint operation of two types of power plants. And will allow to make instant adjustments of their generation.

Given the fact that 15 thermal power plants and more than 40 CHPs have been installed in Ukraine, most of which are partially out of operation, there is a large environment for efficient and economical use of such a combination and, accordingly, the proposed monitoring module.

Equally important is the fact that the task of reducing the use of fossil fuels will significantly empty the area set aside for ash dumps for its storage. After storing coal and ash on the ground, it becomes unsuitable for building or planting crops. And, accordingly, the installation of the station on the territory of the ash dump reduces the cost of purchasing a large area of land.

Also, monitoring will simplify the forecasting of the solar power plant, as it will have access to regulate the load of TPP power units and the frequency of electricity.

In Ukraine, there are analogues of regulating the operation of a thermal power plant or power plant, but such system is not able to control the load of power units in accordance with the current state of generation of a solar power plant.

In Europe, competitors are represented by such manufacturers as Fronius, SMA, Solar Edge. And several manufacturers from China, such as Huawei or Solis.

These monitoring analogues work exclusively in the operation of a solar power plant and in real time allow to obtain information about:

- evaluation of current data (voltage, current, performance, etc.);
- the state of the system and the quality of the connection;
- condition of automation and protection devices;
- presence of damaged or disabled parts.

But, in contrast to the proposed model, all programs that are represented by competitors, designed to regulate only the work of SPP.

4.2 Technological audit of the project idea

Before implementing the project on the common market, it is necessary to argue the technological feasibility of the project. To check the feasibility of the technological audit, I analyze Table 4.1.

Table 4.1 – Technological feasibility of the project idea.

№	Project idea	Technologies of its realization	Presence of technologies	Availability of technologies
1	Creation of a software module for monitoring the efficiency of the combination of thermal and solar power plants	Programming language JavaScript	Technology is present	Technology available
2		C ++ programming language	Technology is present	Technology available

Selected technology for implementing the project idea: all above technologies play a significant role in the formation and development of software and the final product as a whole.

4.3 Analysis of market opportunities to start a startup project

Determining the possibilities of market implementation of the project allows to plan the directions of project development taking into account the state of the market environment, the needs of potential clients and the proposals of competing projects (Table 4.2).

Table 4.2 – Opportunity factors.

№	Factor	Content of the opportunity	Possible reaction of the company
1	Monopoly in the market	After the release of the product and the study of the situation there is a possibility that the product will be the only competitive in the market.	Improve the product in order to be accessible to a large number of users.
2	Government supports the use of software.	Involvement of state funds or public organizations in cooperation in order to use software for design companies.	Product advertising

Identification of market threats that may hinder the implementation of the project, taking into account the state of the market environment, the needs of potential customers and proposals of competing projects (Table 4.3).

Table 4.3 – Threat factors.

№	Factor	Threat content	Possible reaction of the company
1	Ban the use of software	The use of developed software may be prohibited at the state level.	Development of the service of individual consultations on legal terms.
2	Distrust of potential customers to the new company	A new product without a name on the market may not inspire confidence in users.	Conducting early marketing campaigns for the target audience.
3	Increasing competition in the market.	The emergence of competing companies will cause an outflow of customers and will affect the financial performance of the business.	Development of the service component, investment in marketing and improvement of the user experience.

The final stage of the market analysis of project implementation opportunities is the compilation of a SWOT-analysis - matrix analysis of strong and weak sides, threats and opportunities, SWOT-analysis is shown in Table 4.4.

Table 4.4 – SWOT - analysis of the startup project.

Strengths:	**Weak sides:**
- the startup project is a monopolist in the Ukrainian market; - a small number of competing companies; - fundamental novelty of the product; - encouraging consumers at the legislative level to use RES; - constant online software support; - full information of the user; - relatively small investment capital costs; - availability of a base of potential customers (existing TPPs and CHPs) that need solutions in this direction.	- no experience in the market; - insufficient support from the state; - lack of a team of IT specialists; - limited number of objects.

Features:	Threats:
- after the release of the product and the study of the situation there is a possibility that the product will be the only competitive market; - software development; - easy access to software; - the possibility of entering the European market as an innovation; - the ability to independently control the limits of electricity produced; - sale by franchise.	- competition; - distrust of potential customers; - problems with creating competitive software; - investment risk is associated with the deterioration of the socio-political and economic state of the economy in the country.

4.4 Development of market strategy of the project

The first step in developing a market strategy involves defining a market coverage strategy: a description of the target groups of potential consumers. The choice of target groups of potential consumers is made in Table 4.5.

Table 4.5 – Selection of target groups of potential consumers.

№	Description of the profile of the target group of potential customers	Readiness of consumers to accept the product	Demand within the target group	Intensity of competition in the segment	Ease of entry into the segment
1	TPP	High	High	Weak	Simple
2	CHP	High	High	Weak	Simple
3	Investors	High	High	Weak	Simple

Which target groups are selected: thermal power plants.

4.5 Development of a marketing program for a startup project

The definition of the key advantages of the potential product concept is shown in Table 4.6.

Table 4.6 - Identify the key benefits of the concept of a potential product.

№	Needs	The benefit offered by the product	Key advantages over competitors (existing or ones you want to create)
1.	Energy efficiency savings	Provides the ability to regulate electricity generation and reduce losses during regulation	The efficiency of the system's response to the mismatch of one of the stations
2.	Ensuring sustainable development and installation of RES	Allows to reduce the use of fossil fuels	Determines the amount of electricity generated by generating systems
3.	Use of the model under any conditions of the TPP or CHP	Has the ability to adapt to various system configurations	Individual approach to software configuration provision in accordance with the needs of the station
4.	Product support and updates	Creates and updates enhancement features	Connected online to a shared server, which allows you to analyze and improve your efficiency

The concept according to which the company carefully considers and coordinates the work of its numerous communication channels is called the concept of marketing communication, it is shown in Table 4.7. The aim is to develop a clear, consistent and compelling understanding among consumers about the product. Aimed at informing, persuading, reminding consumers and the market as a whole about the product and activities.

Table 4.7 – The concept of marketing communication.

№	Target groups	Communication channels, which enjoy targeted customers	Key items selected for positioning	Tasks of the advertising message	The concept of the advertising address
1.	TPP	Internet	Reliability, completeness of information, quality, innovation	To interest customers, to disseminate information	Prospects, reliability, reliability
2.	CHP	Internet	Reliability, completeness of information, quality, innovation	To interest customers, to disseminate information	Prospects, reliability, reliability
3.	Investors	Internet	Reliability, completeness of information, quality, innovation	To interest customers, disseminate information	Prospects, reliability, reliability

Conclusions to Section 4

The idea of startup project, which has been developed, is to create a software module for monitoring the efficiency of the combination of thermal and solar power plants. The project provides the user with the opportunity to receive recommendations on the technology (techniques) of energy saving based on the use of combination of SPP and TPP systems.

Analysis of market opportunities to launch a startup project showed that this product is vulnerable to threats such as distrust of potential customers to the new company and growing market competition and investment risk associated with deteriorating socio-political and economic situation in the country.

The study revealed that the greatest demand among all target groups will be managers of thermal power plants and CHP.

The analysis showed that the barrier to the implementation of the startup project will be the lack of market experience and insufficient support from the state.

The review showed that supporting the project online and regularly updating the product software makes it possible to be commercially attractive in the future with possible competition.

CONCLUSIONS

In this desertation, an analysis of guaranteed power supply systems was performed and the existing methods and classifications of such systems were considered.

In first section, an analysis of the legal framework on consumer reliability was conducted. Based on the analysis, I can conclude that the issue of security is quite relevant not only in the scale of industry or the life of each consumer, but in general for the integrated power system. As a backup source, many resources can be used, one of which is solar energy. An extensive analysis of existing industrial stations, which became the basis for further development, was conducted. At the moment, Ukraine has been able to show that the rapid growth of RES development can be realized only with the right tasks and sound actions to implement them.

In second section, the tendencies of decrease in the use of fossil fuels, in particular coal, are revealed. The main tasks set for the station staff are analyzed and the main ways of realization of these tasks are determined. The main features of operation and production of electricity by different types of stations, in particular TPPs and CHPs, are considered. The impact of the stations on the quality of electricity and balance reliability was also assessed.

Based on the analysis, it can be concluded that due to the maneuverability of the thermal power plant, it is best suited for installation and connection to its system, solar station. Another important criterion is the fact that legislative obligations have been imposed to reduce the production of electricity using fossil fuels, which in turn has led to a reduction in the area used for the ash dump. This territory can be used for installation of SPP.

The analysis of third station was carried out in connection with the rapid development of RES in Ukraine. The main stimulus for investment in the SPP was "green tariffs" and regulation of the energy market in Ukraine in general.

Based on the technical calculations in this project, I can conclude that with an increase in the total capacity of photomodules and an inverter load of 120%, the annual amount of energy produced can be significantly improved. Also, to increase the productivity of the station, it is important to find the optimal angle of inclination of the structures with panels and the distance between them to prevent shading. At the same time, the operation of the station during operation is affected by the degradation factor of the modules.

According to economic calculations, I determined that after eleven years of the station operation, I received a negative value of NPV, which amounted to approximately one million 568 thousand 420.16 dollars. As in the period after the study the "green" tariff will no longer apply in Ukraine, the issue of full payback is quite difficult. It is impossible to predict the profitability of the station for that period.

Based on IRR calculations, it can be concluded that the profitability of the station is -9.02% and in terms of payback, it is not attractive. However, it is important to understand that with the use of this system as a reserve and a way to regulate the operation of CHP, there is a financial benefit for the overall operation of the IPS (Integrated Power System) of Ukraine. This makes the station attractive to investors.

Therefore, this study may be useful for the further development of solar energy in Ukraine.

The idea of startup project, which has been developed, is to create a software module for monitoring the efficiency of the combination of thermal and solar power plants. The project provides the user with the opportunity to receive recommendations on the technology (techniques) of energy saving based on the use of combination of SPP and TPP systems. The study revealed that the greatest demand among all target groups will be managers of thermal power plants and CHP. The analysis showed that the barrier to the implementation of the startup project will be the lack of market experience and insufficient support from the state. The review showed that supporting the project online and regularly updating the product software makes it possible to be commercially attractive in the future with possible competition.

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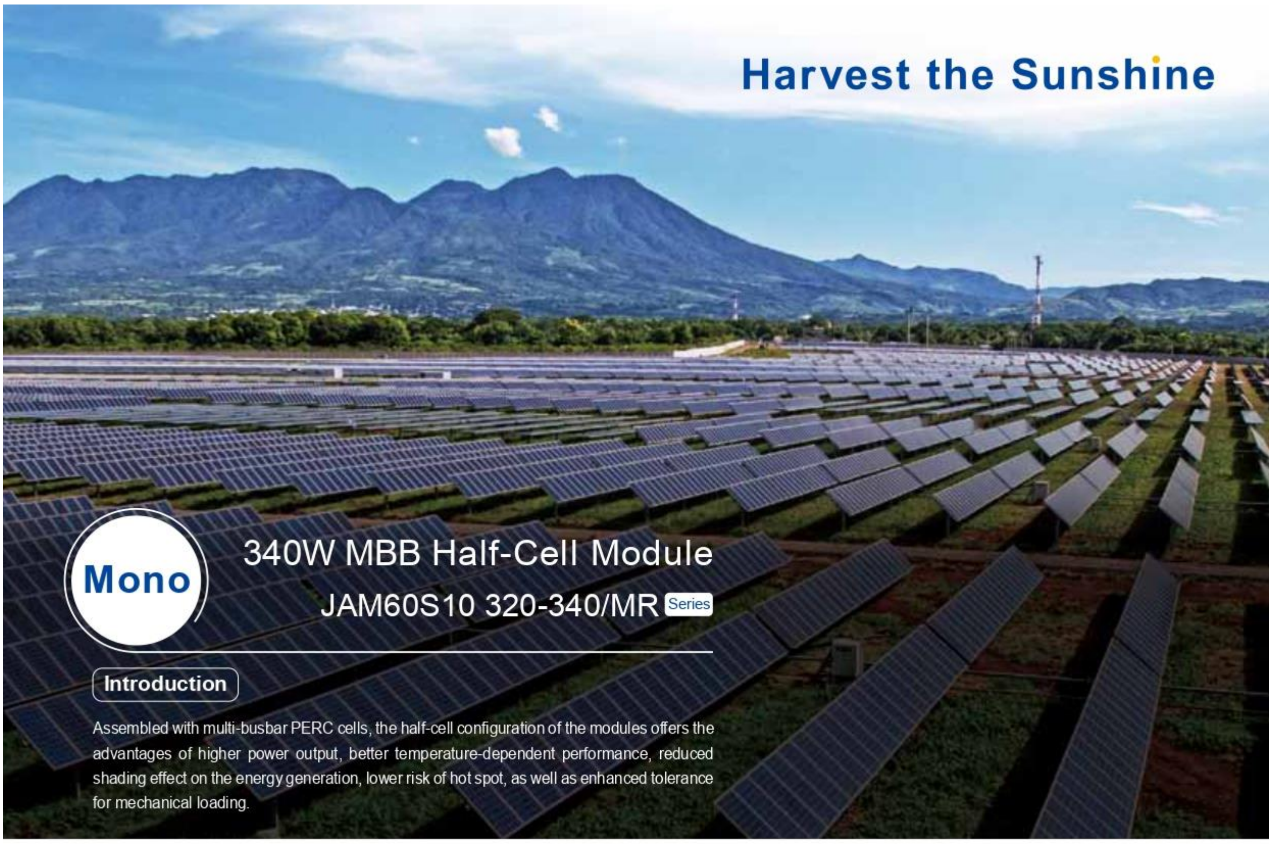
ANNEXES

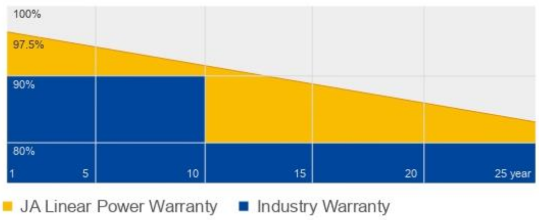
Annex A



- Higher output power
- Lower LCOE
- Less shading and lower resistive loss
- Better mechanical loading tolerance

Superior Warranty

- 12-year product warranty
- 25-year linear power output warranty



Comprehensive Certificates

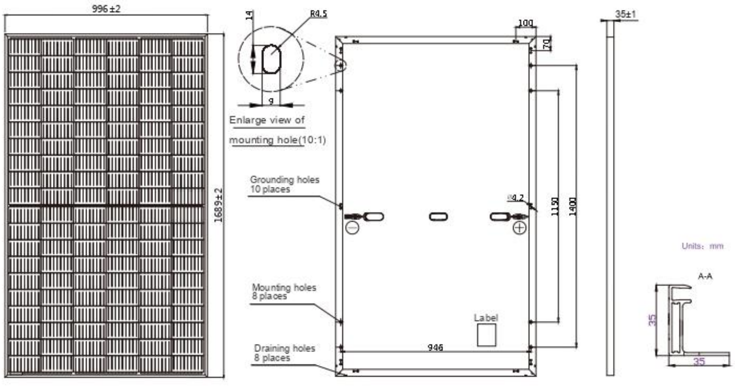
- IEC 61215, IEC 61730
- ISO 9001: 2015 Quality management systems
- ISO 14001: 2015 Environmental management systems
- OHSAS 18001: 2007 Occupational health and safety management systems
- IEC TS 62941: 2016 Terrestrial photovoltaic (PV) modules – Guidelines for increased confidence in PV module design qualification and type approval

JA SOLAR

www.jasolar.com

Specifications subject to technical changes and tests.
JA Solar reserves the right of final interpretation.

MECHANICAL DIAGRAMS



Remark: customized frame color and cable length available upon request

SPECIFICATIONS

Cell	Mono
Weight	19.0kg±3%
Dimensions	1689±2mm×996±2mm×35±1mm
Cable Cross Section Size	4mm²
No. of cells	120(6×20)
Junction Box	IP68, 3 diodes
Connector	QC 4.10-35
Cable Length (Including Connector)	Portrait:300mm(+)/400mm(-); Landscape:1000mm(+)/1000mm(-)
Packaging Configuration	30 Per Pallet

ELECTRICAL PARAMETERS AT STC

TYPE	JAM60S10 -320/MR	JAM60S10 -325/MR	JAM60S10 -330/MR	JAM60S10 -335/MR	JAM60S10 -340/MR
Rated Maximum Power(Pmax) [W]	320	325	330	335	340
Open Circuit Voltage(Voc) [V]	40.60	40.87	41.08	41.32	41.55
Maximum Power Voltage(Vmp) [V]	33.73	33.97	34.24	34.48	34.73
Short Circuit Current(Isc) [A]	10.16	10.23	10.30	10.38	10.46
Maximum Power Current(Imp) [A]	9.49	9.57	9.64	9.72	9.79
Module Efficiency [%]	19.0	19.3	19.6	19.9	20.2
Power Tolerance	0~+5W				
Temperature Coefficient of Isc(α_Isc)	+0.044%/℃				
Temperature Coefficient of Voc(β_Voc)	-0.272%/℃				
Temperature Coefficient of Pmax(γ_Pmp)	-0.350%/℃				
STC	Irradiance 1000W/m², cell temperature 25℃, AM1.5G				

Remark: Electrical data in this catalog do not refer to a single module and they are not part of the offer.They only serve for comparison among different module types.

ELECTRICAL PARAMETERS AT NOCT

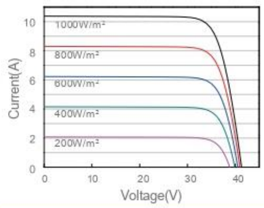
TYPE	JAM60S10 -320/MR	JAM60S10 -325/MR	JAM60S10 -330/MR	JAM60S10 -335/MR	JAM60S10 -340/MR
Rated Max Power(Pmax) [W]	241	245	249	253	257
Open Circuit Voltage(Voc) [V]	38.05	38.26	38.46	38.68	38.90
Max Power Voltage(Vmp) [V]	31.58	31.80	32.02	32.21	32.40
Short Circuit Current(Isc) [A]	8.07	8.14	8.21	8.28	8.35
Max Power Current(Imp) [A]	7.63	7.70	7.78	7.85	7.93
NOCT	Irradiance 800W/m², ambient temperature 20℃, wind speed 1m/s, AM1.5G				

OPERATING CONDITIONS

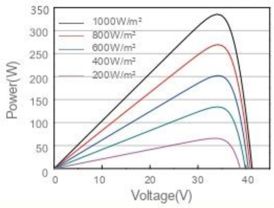
Maximum System Voltage	1000V/1500V DC(IEC)
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	20A
Maximum Static Load,Front	5400Pa
Maximum Static Load,Back	2400Pa
NOCT	45±2℃
Application Class	Class A

CHARACTERISTICS

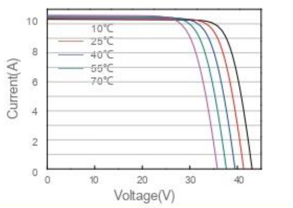
Current-Voltage Curve JAM60S10-335/MR



Power-Voltage Curve JAM60S10-335/MR



Current-Voltage Curve JAM60S10-335/MR



Annex B

victron energy
BLUE POWER

Quattro Inverter/Charger

3kVA - 15kVA Lithium Ion battery compatible www.victronenergy.com

Quattro
48/5000/70-100/100

Quattro
48/15000/200-100/100

Two AC inputs with integrated transfer switch

The Quattro can be connected to two independent AC sources, for example the public grid and a generator, or two generators. The Quattro will automatically connect to the active source.

Two AC Outputs

The main output has no-break functionality. The Quattro takes over the supply to the connected loads in the event of a grid failure or when shore/generator power is disconnected. This happens so fast (less than 20 milliseconds) that computers and other electronic equipment will continue to operate without disruption.
The second output is live only when AC is available on one of the inputs of the Quattro. Loads that should not discharge the battery, like a water heater for example, can be connected to this output.

Virtually unlimited power thanks to parallel operation

Up to 6 Quattro units can operate in parallel. Six units 48/10000/140, for example, will provide 48kW / 60kVA output power and 840 Amps charging capacity.

Split phase options

Two units can be stacked to provide 120-0-120V, and additional units can be paralleled up to a total of 6 units per phase, to supply up to 30kW / 36kVA of split phase power.
Alternatively, a split phase AC source can be obtained by connecting our autotransformer (see data sheet on www.victronenergy.com) to a 'European' inverter programmed to supply 240V / 60Hz.

Three phase capability

Three units can be configured for three phase output. But that's not all: up to 6 sets of three units can be parallel connected to provide 144kW / 180kVA inverter power and more than 2500A charging capacity.

PowerControl – Dealing with limited generator, shore side or grid power

The Quattro is a very powerful battery charger. It will therefore draw a lot of current from the generator or shore side supply (16A per 5kVA Quattro at 230VAC). A current limit can be set on each AC input. The Quattro will then take account of other AC loads and use whatever is spare for charging, thus preventing the generator or mains supply from being overloaded.

PowerAssist – Boosting shore or generator power

This feature takes the principle of PowerControl to a further dimension allowing the Quattro to supplement the capacity of the alternative source. Where peak power is so often required only for a limited period, the Quattro will make sure that insufficient mains or generator power is immediately compensated for by power from the battery. When the load reduces, the spare power is used to recharge the battery.

Solar energy: AC power available even during a grid failure

The Quattro can be used in off grid as well as grid connected PV and other alternative energy systems.
Loss of mains detection software is available.

System configuring

- In case of a stand-alone application, if settings have to be changed, this can be done in a matter of minutes with a DIP switch setting procedure.
- Parallel and three phase applications can be configured with VE.Bus Quick Configure and VE.Bus System Configurator software.
- Off grid, grid interactive and self-consumption applications, involving grid-tie inverters and/or MPPT Solar Chargers can be configured with Assistants (dedicated software for specific applications).

On-site Monitoring and control

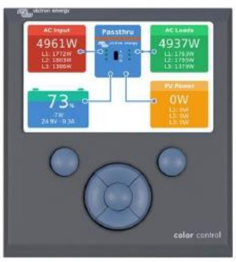
Several options are available: Battery Monitor, Multi Control Panel, Color Control GX or other GX devices, smartphone or tablet (Bluetooth Smart), laptop or computer (USB or RS232).

Remote Monitoring and control

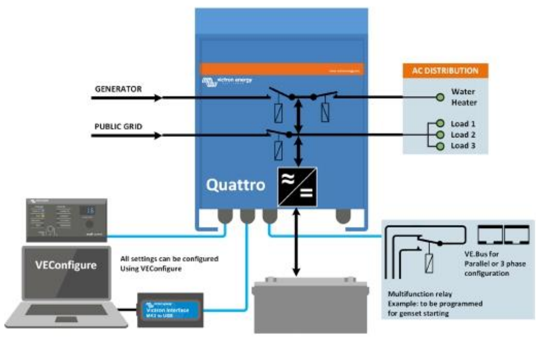
Color Control GX or other GX devices.
Data can be stored and displayed on our VRM (Victron Remote Management) website, free of charge.

Remote configuring

When connected to the Ethernet, systems with a Color Control GX or other GX device can be accessed and settings can be changed remotely.



Color Control GX, showing a PV application



Quattro	12/3000/120-50/50 24/3000/70-50/50	12/5000/220-100/100 24/5000/120-100/100 48/5000/70-100/100	24/8000/200-100/100 48/8000/110-100/100	48/10000/140-100/100	48/15000/200-100/100
PowerControl / PowerAssist	Yes				
Integrated Transfer switch	Yes				
AC inputs (2x)	Input voltage range: 187-265 VAC Input frequency: 45 – 65 Hz Power factor: 1				
Maximum feed through current (A)	2x50	2x100	2x100	2x100	2x100
INVERTER					
Input voltage range (V DC)	9,5 – 17V 19 – 33V 38 – 66V				
Output (1)	Output voltage: 230 VAC ± 2% Frequency: 50 Hz ± 0,1%				
Cont. output power at 25°C (VA) (3)	3000	5000	8000	10000	15000
Cont. output power at 25°C (W)	2400	4000	6500	8000	12000
Cont. output power at 40°C (W)	2200	3700	5500	6500	10000
Cont. output power at 65°C (W)	1700	3000	3600	4500	7000
Peak power (W)	6000	10000	16000	20000	25000
Maximum efficiency (%)	93 / 94	94 / 94 / 95	94 / 96	96	96
Zero load power (W)	20 / 20	30 / 30 / 35	60 / 60	60	110
Zero load power in AES mode (W)	15 / 15	20 / 25 / 30	40 / 40	40	75
Zero load power in Search mode (W)	8 / 10	10 / 10 / 15	15 / 15	15	20
CHARGER					
Charge voltage 'absorption' (V DC)	14,4 / 28,8	14,4 / 28,8 / 57,6	28,8 / 57,6	57,6	57,6
Charge voltage 'float' (V DC)	13,8 / 27,6	13,8 / 27,6 / 55,2	27,6 / 55,2	55,2	55,2
Storage mode (V DC)	13,2 / 26,4	13,2 / 26,4 / 52,8	26,4 / 52,8	52,8	52,8
Charge current house battery (A) (4)	120 / 70	220 / 120 / 70	200 / 110	140	200
Charge current starter battery (A)	4 (12V and 24V models only)				
Battery temperature sensor	Yes				
GENERAL					
Auxiliary output (A) (5)	25	50	50	50	50
Programmable relay (6)	3x	3x	3x	3x	3x
Protection (2)	a-g				
VE.Bus communication port	For parallel and three phase operation, remote monitoring and system integration				
General purpose com. port	2x	2x	2x	2x	2x
Remote on-off	Yes				
Common Characteristics	Operating temp.: -40 to +65˚C Humidity (non-condensing): max. 95%				
ENCLOSURE					
Common Characteristics	Material & Colour: aluminium (blue RAL 5012) Protection category: IP 21				
Battery-connection	Four M8 bolts (2 plus and 2 minus connections)				
230 V AC-connection	Screw terminals 13 mm² (6 AWG)	Bolts M6	Bolts M6	Bolts M6	Bolts M6
Weight (kg)	19	34 / 30 / 30	45 / 41	51	72
Dimensions (hxwxd in mm)	362 x 258 x 218	470 x 350 x 280 444 x 328 x 240 444 x 328 x 240	470 x 350 x 280	470 x 350 x 280	572 x 488 x 344
STANDARDS					
Safety	EN-IEC 60335-1, EN-IEC 60335-2-29, EN-IEC 62109-1				
Emission, Immunity	EN 55014-1, EN 55014-2, EN-IEC 61000-3-2, EN-IEC 61000-3-3, IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3				
Road vehicles	12V and 24V models: ECE R10-4				
Anti-islanding	See our website				

1) Can be adjusted to 60 HZ. 120 V models available on request
2) Protection key:
- a) output short circuit
- b) overload
- c) battery voltage too high
- d) battery voltage too low
- e) temperature too high
- f) 230 VAC on inverter output
- g) input voltage ripple too high

3) Non-linear load, crest factor 3:1
4) At 25˚C ambient
5) Switches off when no external AC source available
6) Programmable relay that can a.o. be set for general alarm, DC under voltage or genset start/stop function
AC rating: 230 V / 4 A
DC rating: 4 A up to 35 VDC, 1 A up to 60 VDC

Digital Multi Control Panel
A convenient and low cost solution for remote monitoring, with a rotary knob to set PowerControl and PowerAssist levels.


VE.Bus Smart Dongle
Measures battery voltage and temperature and allows monitoring and control of Multis and Quattros with a smartphone or other Bluetooth enabled device.

Computer controlled operation and monitoring
Several interfaces are available:

Color Control GX and other GX devices
Monitoring and control. Locally, and also remotely on the VRM Portal.

MK3-USB (VE.Bus to USB interface)
Connects to a USB port (see 'A guide to VEConfigure')

VE.Bus to NMEA 2000 interface
Connects the device to a NMEA2000 marine electronics network. See the NMEA2000 & MFD integration guide

BMV-712 Smart Battery Monitor
Use a smartphone or other Bluetooth enabled device to:
- customize settings,
- monitor all important data on single screen,
- view historical data, and to
- update the software when new features become available.

Annex C

SmartSolar Charge Controllers with VE.Can interface

MPPT 150/70 VE.Can up to MPPT 150/100 VE.Can

SmartSolar Charge Controller
MPPT 150/100-Tr VE.Can
with optional pluggable display

SmartSolar Charge Controller
MPPT 150/100-Tr VE.Can
without display

Bluetooth sensing:
Smart Battery Sense

Bluetooth sensing:
BMV-712 Smart Battery Monitor

Ultra-fast Maximum Power Point Tracking (MPPT)
Especially in case of a clouded sky, when light intensity is changing continuously, an ultra-fast MPPT controller will improve energy harvest by up to 30% compared to PWM charge controllers and by up to 10% compared to slower MPPT controllers.

Advanced Maximum Power Point Detection in case of partial shading conditions
If partial shading occurs, two or more maximum power points (MPP) may be present on the power-voltage curve.
Conventional MPPTs tend to lock to a local MPP, which may not be the optimum MPP.
The innovative SmartSolar algorithm will always maximize energy harvest by locking to the optimum MPP.

Outstanding conversion efficiency
No cooling fan. Maximum efficiency exceeds 98%.

Flexible charge algorithm
Fully programmable charge algorithm, and eight pre-programmed algorithms, selectable with a rotary switch (see manual for details).

Extensive electronic protection
Over-temperature protection and power derating when temperature is high.
PV short circuit and PV reverse polarity protection.
PV reverse current protection.

Bluetooth Smart built-in
The wireless solution to set-up, monitor, update and synchronise SmartSolar Charge Controllers.

Internal temperature sensor and optional external battery voltage and temperature sensing via Bluetooth
A Smart Battery Sense or a BMV-712 Smart Battery Monitor can be used to communicate battery voltage and temperature to one or more SmartSolar Charge Controllers.

Fully discharged battery recovery function
Will initiate charging even if the battery has been discharged to zero volts.
Will reconnect to a fully discharged Li-ion battery with integrated disconnect function.

VE.Can: the multiple controller solution
Up to 25 units can be synchronised with VE.Can

VE.Direct or VE.Can
For a wired data connection to a Color Control GX, other GX products, PC or other devices

Remote on-off
To connect for example to a VE.BUS BMS.

Programmable relay
Can be programmed to trip on an alarm,
or other events.

Optional: SmartSolar pluggable LCD display
Simply remove the rubber seal that protects
the plug on the front of the controller,
and plug-in the display.

SmartSolar pluggable display

Victron Energy B.V. | De Paal 35 | 1351 JG Almere | The Netherlands
General phone: +31 (0)36 535 97 00 | E-mail: sales@victronenergy.com
www.victronenergy.com

SmartSolar Charge Controller with VE.Can interface	150/70 VE.Can	150/85 VE.Can	150/100 VE.Can (also available without Bluetooth)
Battery voltage	12/24/48V Auto Select (36V: manual)		
Rated charge current	70A	85A	100A
Nominal PV power, 12V 1a,b)	1000W	1200W	1450W
Nominal PV power, 24V 1a,b)	2000W	2400W	2900W
Nominal PV power, 36V 1a,b)	3000W	3600W	4350W
Nominal PV power, 48V 1a,b)	4000W	4900W	5800W
Max. PV short circuit current 2)	50A (max 30A per MC4 conn.)	70A (max 30A per MC4 conn.)	
Maximum PV open circuit voltage	150V absolute maximum coldest conditions 145V start-up and operating maximum		
Maximum efficiency	98%		
Self-consumption	Less than 35mA @ 12V / 20mA @ 48V		
Charge voltage 'absorption'	Default setting: 14,4 / 28,8 / 43,2 / 57,6V (adjustable with: rotary switch, display, VE.Direct or Bluetooth)		
Charge voltage 'float'	Default setting: 13,8 / 27,6 / 41,4 / 55,2V (adjustable: rotary switch, display, VE.Direct or Bluetooth)		
Charge voltage 'equalization'	Default setting: 16,2V / 32,4V / 48,6V / 64,8V (adjustable)		
Charge algorithm	multi-stage adaptive (eight preprogrammed algorithms) or user defined algorithm		
Temperature compensation	-16 mV / -32 mV / -64 mV / °C		
Protection	PV reverse polarity / Output short circuit / Over temperature		
Operating temperature	-30 to +60°C (full rated output up to 40°C)		
Humidity	95%, non-condensing		
Maximum altitude	5000m (full rated output up to 2000m)		
Environmental condition	Indoor, unconditioned		
Pollution degree	PD3		
Data communication	VE.Can, VE.Direct and Bluetooth		
Remote on/off	Yes (2 pole connector)		
Programmable relay	DPST AC rating: 240VAC / 4A DC rating: 4A up to 35VDC, 1A up to 60VDC		
Parallel operation	Yes, parallel synchronised operation with VE.Can or Bluetooth		
ENCLOSURE			
Colour	Blue (RAL 5012)		
PV terminals 3)	35 mm² / AWG2 (Tr models) Two pairs of MC4 connectors (MC4 models)	35 mm² / AWG2 (Tr models) Three pairs of MC4 connectors (MC4 models)	
Battery terminals	35mm² / AWG2		
Protection category	IP43 (electronic components), IP22 (connection area)		
Weight	3 kg	4,5kg	
Dimensions (h x w x d) in mm	Tr models: 185 x 250 x 95 mm MC4 models: 215 x 250 x 95 mm	Tr models: 216 x 295 x 103 MC4 models: 246 x 295 x 103	
STANDARDS			
Safety	EN/IEC 62109-1, UL 1741, CSA C22.2		

1a) If more PV power is connected, the controller will limit input power.
1b) The PV voltage must exceed Vbat + 5V for the controller to start. Thereafter the minimum PV voltage is Vbat + 1V.
2) A PV array with a higher short circuit current may damage the controller.
3) MC4 models: several splitter pairs may be needed to parallel the strings of solar panels
Maximum current per MC4 connector: 30A (the MC4 connectors are parallel connected to one MPPT tracker)

With VE.Can or Bluetooth up to 25 respectively up to 10 Charge Controllers can be daisy-chained for synchronous charging and connected to a Color Control GX or other GX device
Each Controller can be monitored individually, for example on a Color Control GX and on the VRM website (VE.Can) or on a smartphone or iPad (Bluetooth)

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General phone: +31 (0)36 535 97 00 | E-mail: sales@victronenergy.com
www.victronenergy.com

Annex D

КОМПЛЕКТНІ ТРАНСФОРМАТОРНІ ПІДСТАНЦІЇ МОДЕРНІЗОВАНІ КТПГСМ-100…1000/10(6)/0,4 У1 ДЛЯ МІСЬКИХ ЕЛЕКТРИЧНИХ МЕРЕЖ

Комплектні трансформаторні підстанції модернізовані потужністю від 100 до 1000 кВ·А напругою 10(6)/0,4 кВ частотою 50 Гц (далі по тексту КТПГСМ) тупикового і прохідного типу, призначені для приймання, перетворення і розподілу електричної енергії в одно-двох променевих і петльових схемах електропостачання міських електричних мереж у районах з помірним кліматом (від - 45°С до + 40°С).

КТПГСМ поставляються в металевій кабіні високої заводської готовності (2КТПГС — в двох кабінах), з монтованим у неї силовим трансформатором, шафами УВНН, РУНН, шафою вуличного освітлення.

У шафі УВН встановлені вимикачі навантаження ВНПР із пружинно-важільним приводом. У відсіку РУНН встановлені рубильники-запобіжники або автоматичні вимикачі, також є загальний облік електроенергії та облік електроенергії вуличного освітлення (при необхідності).

На вимогу замовника КТПГСМ може поставлятися по індивідуальних схемах замовника.

По бажанню замовника КТПГСМ тупикового типу виготовляються з обліком електроенергії на високій стороні і з вакуумними вимикачами BB/TEL-10.20/630.

По замовленню споживача у відсіку РУНН встановлюються панелі ЩО-94 з АВР на стороні 0,4 кВ. При цьому довжина кабіни — 4540 мм.

Поставляються також КТПГСМ із встановленими в шафах УВН блоками RM6 виробництва «Schneider Electric» з елегазовою ізоляцією. У шафах РУНН на вводі встановлений вимикач Masterpact M20N1 (виробництва «Schneider Electric») на номінальний струм до 2000 А з регулюванням сили струму на відключення, на відхідних лініях рубильники-запобіжники Multivert на номінальний струм до 630 А, виробництва «Schneider Electric» або інших фірм.

Вводи ВН — повітряні або кабельні, виводи НН — кабельні.

КТПГСМ встановлюється на фундамент висотою не менше 200 мм.

Основні параметри КТПГСМ

Потужність, кВ·А	Номінальний струм, А і кількість відхідних ліній			Струм термічної стійкості на стороні ВН, кА	Струм електродинамічної стійкості на стороні ВН, кА	Маса, кг
100	100 – 2 шт.			4	12,5	2675
160	100 – 2 шт.	250 – 1 шт.		4	12,5	2980
250	100 – 2 шт.	250 – 1 шт.	400 – 1 шт.	10	23	3260
400	100 – 2 шт.	250 – 2 шт.	400 – 2 шт.	20	51	3650
630	100 – 4 шт.	250 – 2 шт.	400 – 2 шт.	20	51	4150
1000	100 – 4 шт.	250 – 2 шт.	400 – 2 шт.	20	51	6000

Габаритні, установчі, приєднувальні розміри та схеми електричні однолінійні приведенні на рисунках 1 – 5.

Приклад замовлення однотрансформаторної підстанції потужністю 1000 кВ·А напругою 10 кВ із шафою вуличного освітлення (Ш), з кабельними вводами ВН (К) з рубильниками-запобіжниками на відхідних лініях — **КТПГСМ-1000/10/0,4-ШК-У1 ТУ 43.49-00213440-004-2000 з рубильниками-запобіжниками на відхідних лініях.**

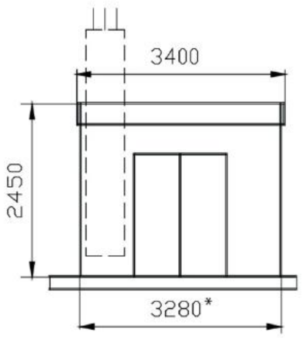
Приклад замовлення двотрансформаторної підстанції потужністю 1000 кВ·А напругою 6 кВ без шафи вуличного освітлення, із двома повітряними вводами ВН (В2) з автоматичними вимикачами на відхідних лініях — **2КТПГС-1000/6/0,4-В2-У1 ТУ 43.49-00213440-004-2000 з автоматичними вимикачами на відхідних лініях.**

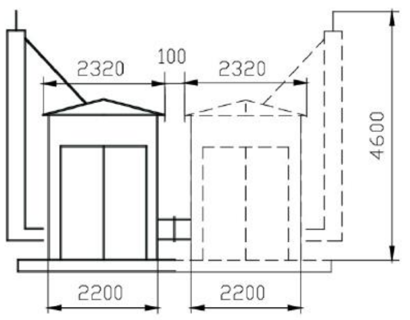
Роз'єднувач лінійний встановлюється за погодженням із замовником.

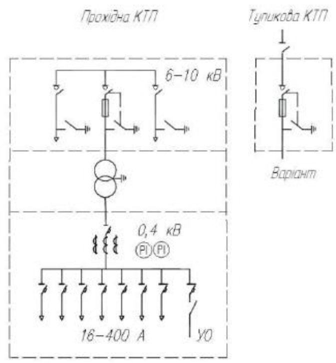
При замовленні КТП необхідно заповнити «**ОПИТУВАЛЬНИЙ ЛИСТ**» і вказати платіжні та відвантажувальні реквізити замовника.

Габаритні розміри КТПГСМ-100…1000/10(6)/0,4 У1

Схема електрична однолінійна







* - для КТПГСМ потужністю до 250 кВ·А

Загальний вигляд КТПГСМ

Загальний вигляд 2КТПГСМ

Установчі та приєднувальні розміри
КТПГСМ-100…1000/10(6)/0,4 У1 прохідна з кабельним вводом

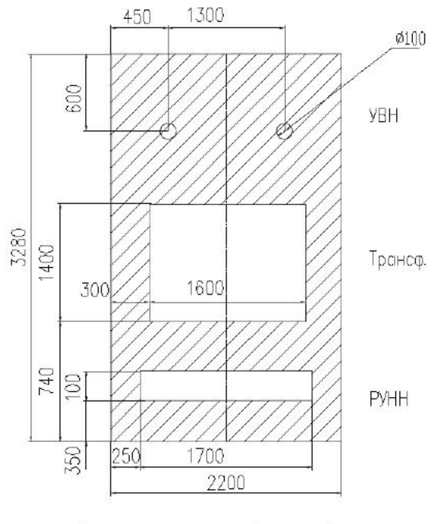
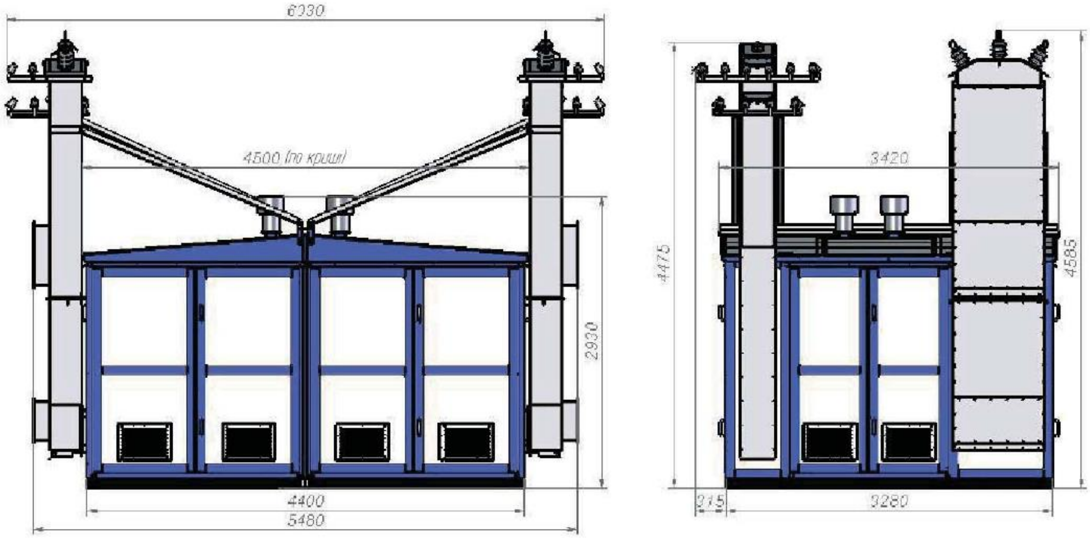


Рис. 1 – Габаритні, установчі, приєднувальні розміри та схема електрична однолінійна КТПГСМ-100…1000/10(6)/0,4 У1.

Варіант виконання 2КТПГСМ у здвоєній кабіні (ввід, вивід повітряний або кабельний)



Варіант виконання 2КТПГСМ в одній кабіні (ввід повітряний або кабельний)

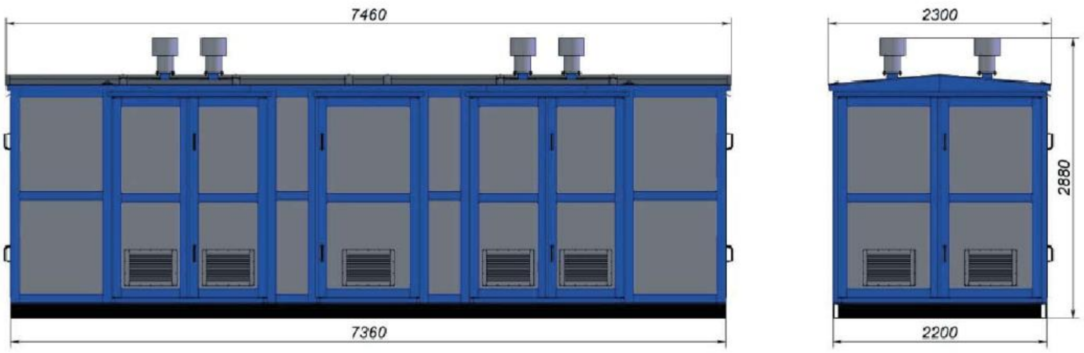


Рис. 2 – Варіанти виконання 2КТПГСМ.

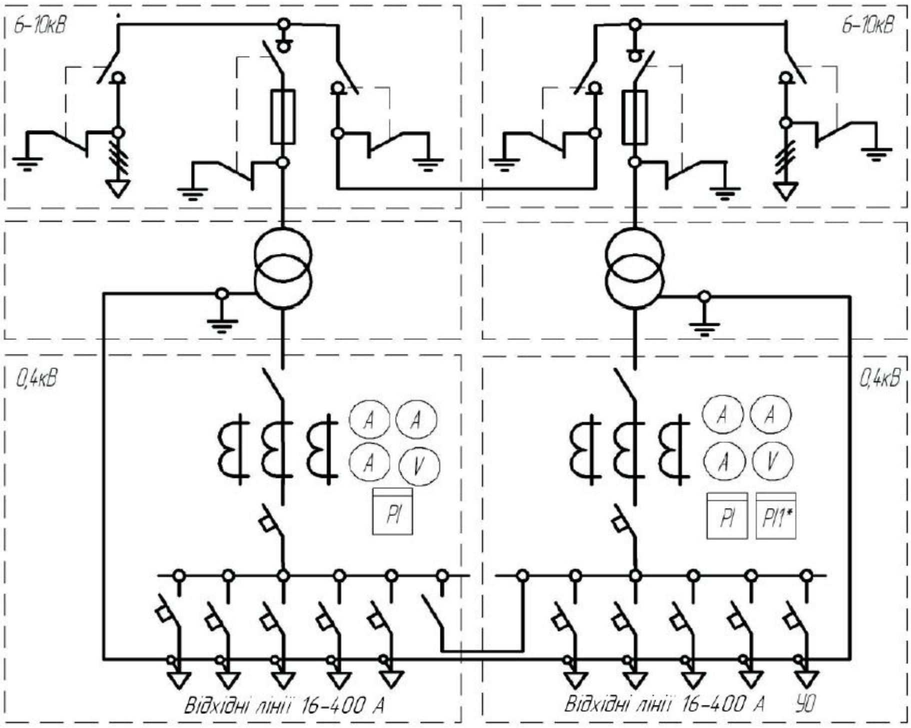


Схема однолінійна 2КТПГСМ

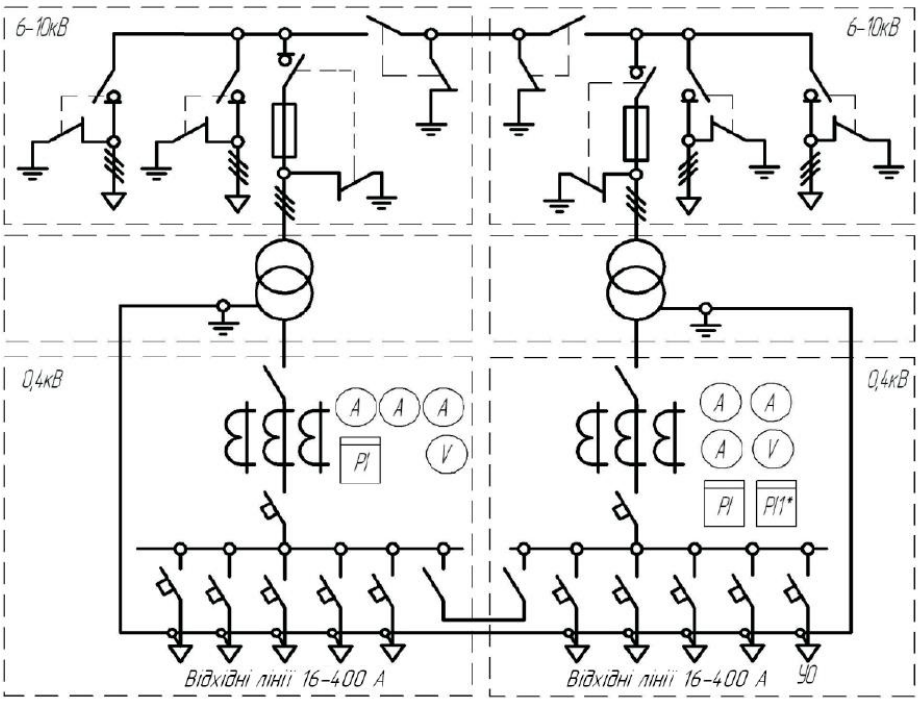
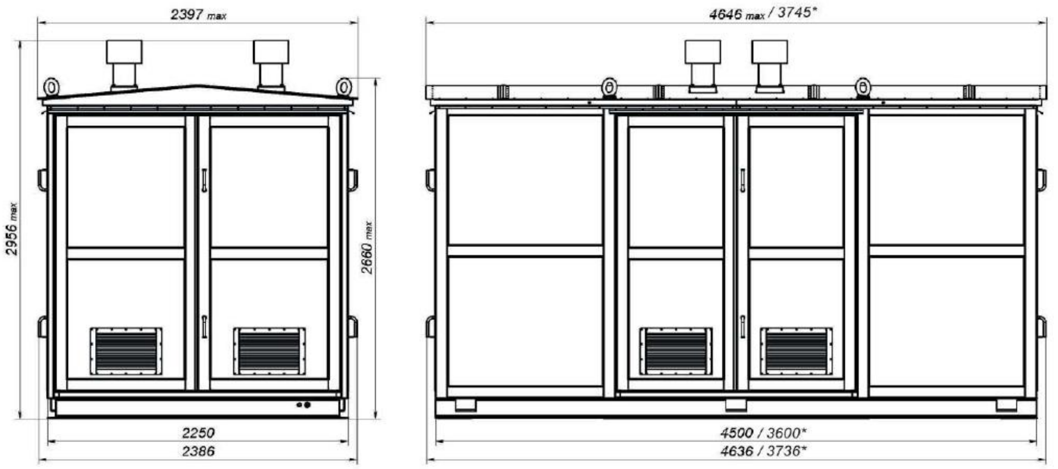


Схема однолінійна 2КТПГСМ з додатковим секційним роз'єднувачем

Рис. 3 – Схеми електричні однолінійні 2КТПГСМ.

Варіант виконання КТПГСМ-1000



* – при установці блоку НН (ШРНН)

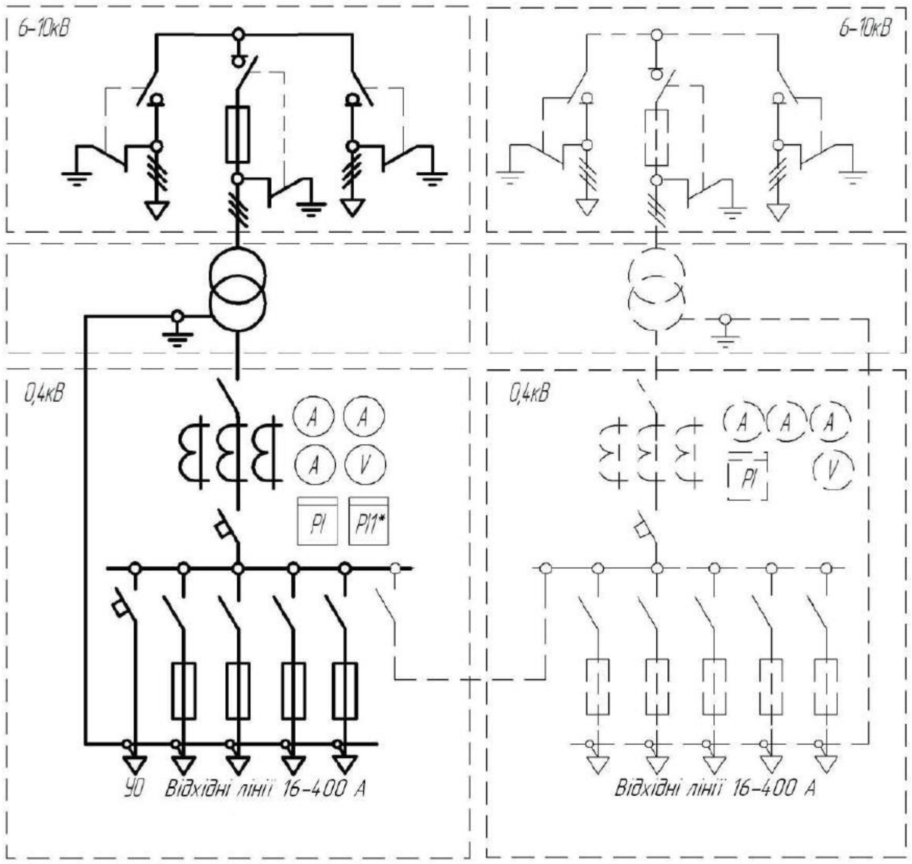
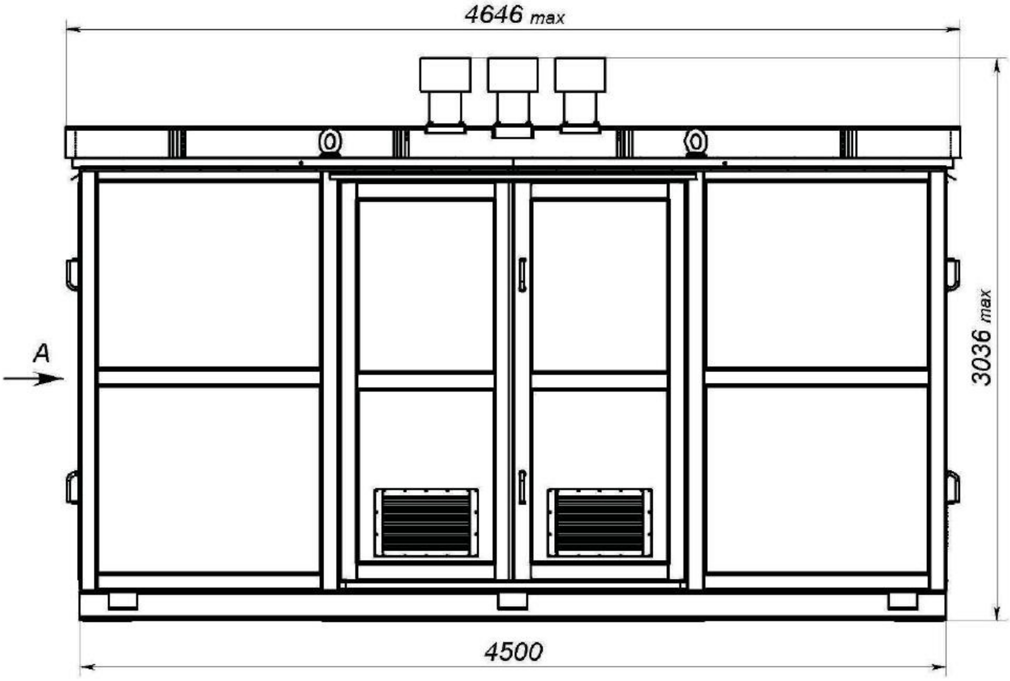


Рис. 4 – Варіант виконання та схема електрична однолінійна КТПГСМ-1000).

Варіант виконання 2КТПГСМ-1000



A

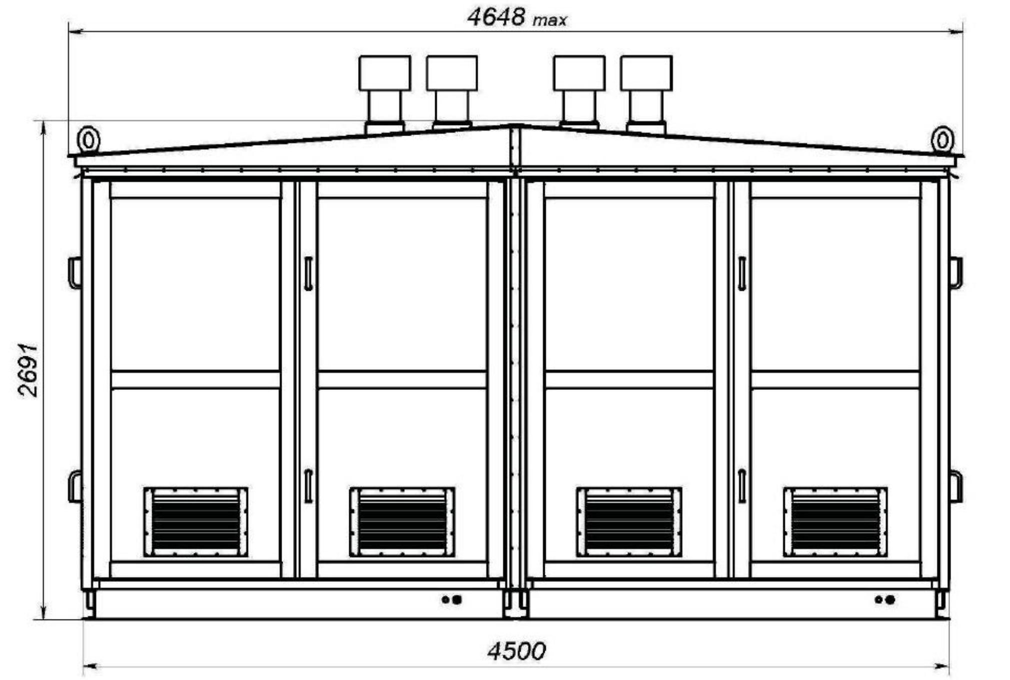


Рис. 5 – Варіант виконання 2КТПГСМ-1000.

Annex E

Color Control GX

www.victronenergy.com

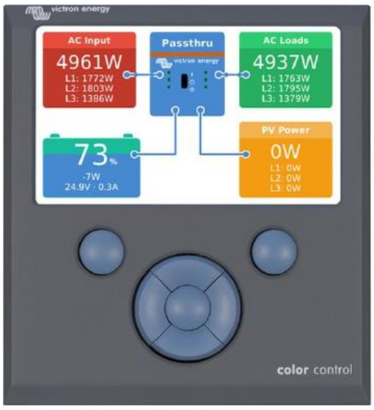
Color Control GX
The Color Control (CCGX) provides intuitive control and monitoring for all Victron power systems. The list of Victron products that can be connected is endless: Inverters, Multis, Quattros, MPPT solar chargers, BMV battery monitors, Lynx Ion + Shunt and more.

VRM Online Portal
Besides monitoring and controlling products locally on the CCGX itself, all readings are also forwarded to our free remote monitoring website: the VRM Online Portal. To get an impression, try the demo on https://vrm.victronenergy.com. See also the screenshots below.

Remote Console on VRM
Monitor, control and configure the CCGX remotely, over the internet. Just like standing in front of the device, everything can also be done remotely. The same functionality is also available on the local network, Remote Console on LAN.

Automatic genset start/stop
A highly customizable start/stop system. Use state of charge, voltage, load and other parameters. Define a special set of rules for quiet times, and optionally a monthly test run.

The heart of ESS – Energy Storage System
The CCGX is the Energy Manager in an ESS system. More information in the ESS manual: https://www.victronenergy.com/live/ess:design-installation-manual



Data logging
When connected to the internet, all data is sent to the VRM Portal. When there is no internet connection available, the CCGX will store the data internally, up to 48 hours. By inserting a micro SD-card or USB stick, more data can be stored. These files can then be uploaded to the VRM Portal, or offline converted with the VictronConnect app, for analysis.

Supported products
- Multis and Quattros, including split-phase and three-phase systems. Monitoring and control (on/off and current limiter). Changing configuration is possible (only remotely via the internet, not without an internet connection).
- BlueSolar MPPT Solar Chargers with a VE.Direct port.
- BlueSolar MPPT 150/70 and the MPPT 150/85 with VE.Can port.
- SmartSolar MPPT 150/70 and the MPPT 150/100 with VE.Can port. When multiple BlueSolar MPPTs or SmartSolar MPPTs with VE.Can are used in parallel, all the information is combined as one. See also our blog-post about synchronizing multiple MPPT 150/70 solar chargers.
- BMV-700 family can be connected directly to the VE.Direct ports on the CCGX. Use the VE.Direct Cable for this.
- BMV-600 family can be connected to the VE.Direct ports on the CCGX. Requires an accessory cable.
- Lynx Ion + Shunt
- Lynx Shunt VE.Can
- Skylla-i battery chargers
- NMEA2000 tank sensors
- A USB GPS can be connected to the USB port. Location and speed will be visible on the display, and the data is sent to the VRM Portal for tracking purposes. The map on VRM will show the latest position.
- Fronius PV Inverters

When more than two VE.Direct products must be connected, USB can be used.

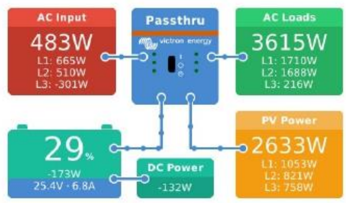
Internet connection
The CCGX can be connected to internet with an Ethernet cable and via wifi. To connect via wifi, a wifi USB accessory is required. The CCGX has no internal cellular modem: there is no slot for a sim-card. Use an off-the-shelf GPRS or 3G router instead. See the blog post about 3G routers.

Other highlights
- The CCGX can automatically update itself from the internet, when there is a new software version available.
- Multiple languages: English, Czech, German, Spanish, French, Italian, Dutch, Russian, Swedish, Turkish, Chinese, Arabic.
- Use the CCGX as a Modbus-TCP gateway to all connected Victron products. See our Modbus-TCP FAQ for more information.
- Powered by the Venus OS – embedded linux. https://github.com/victronenergy/venus/wiki/sales-pitch

Color Control GX

Color Control GX			
Power supply voltage range	8 – 70V DC		
Current draw	12V DC	24V DC	48V DC
Display off	140mA	80mA	40mA
Display at minimum intensity	160mA	90mA	45mA
Display at maximum intensity	245mA	125mA	65mA
Potential free contact	3A / 30V DC / 250V AC (Normally open)		
	Communication ports		
VE.Direct	2 separate VE.Direct ports – isolated		
VE.Can	2 paralleled RJ45 sockets – isolated		
VE.Bus	2 paralleled RJ45 sockets – isolated		
USB	2 USB Host ports – not isolated		
Ethernet	10/100/1000MB RJ45 socket – isolated except shield		
	3rd party interfacing		
Modbus-TCP	Use Modbus-TCP to monitor and control all products connected to the Color Control GX		
JSON	Use the VRM JSON API to retrieve data from the VRM Portal		
	Other		
Outer dimensions (h x w x d)	130 x 120 x 28mm		
Operating temperature range	-20 to +50°C		
	Standards		
Safety	EN 60950-1:2005+A1:2009+A2:2013		
EMC	EN 61000-6-3, EN 55014-1, EN 61000-6-2, EN 61000-6-1, EN 55014-2		
Automotive	E4-10R-053535		

Overview - Multi with PV Inverter on output

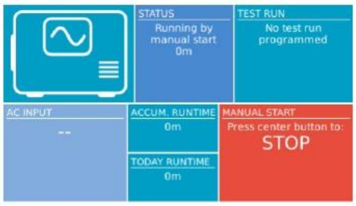


Main menu

Mobile & boat overview

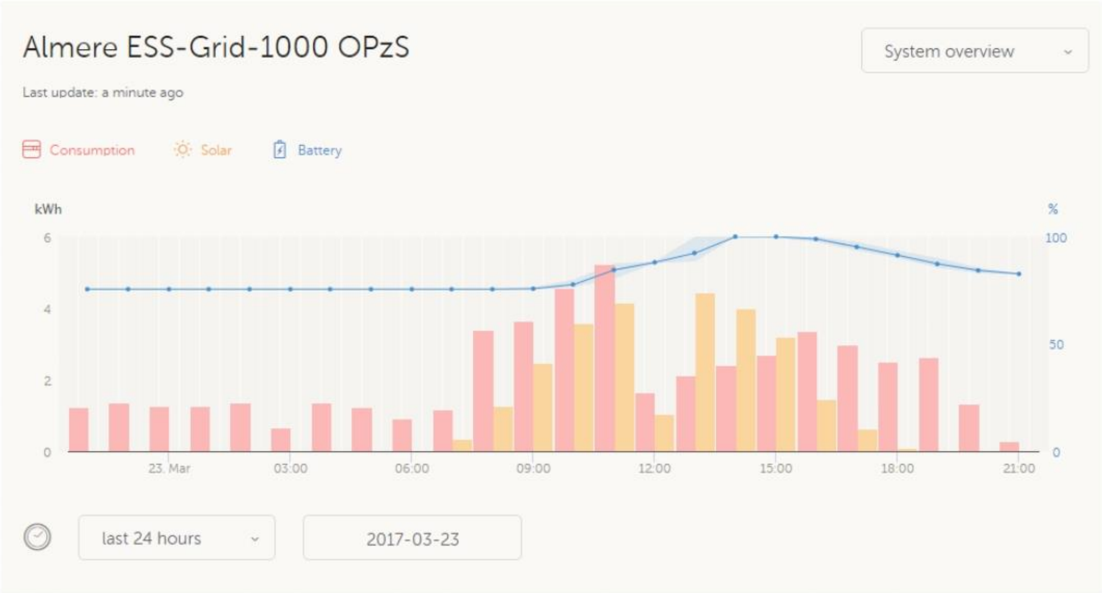
Alarm notifications

Genset control page

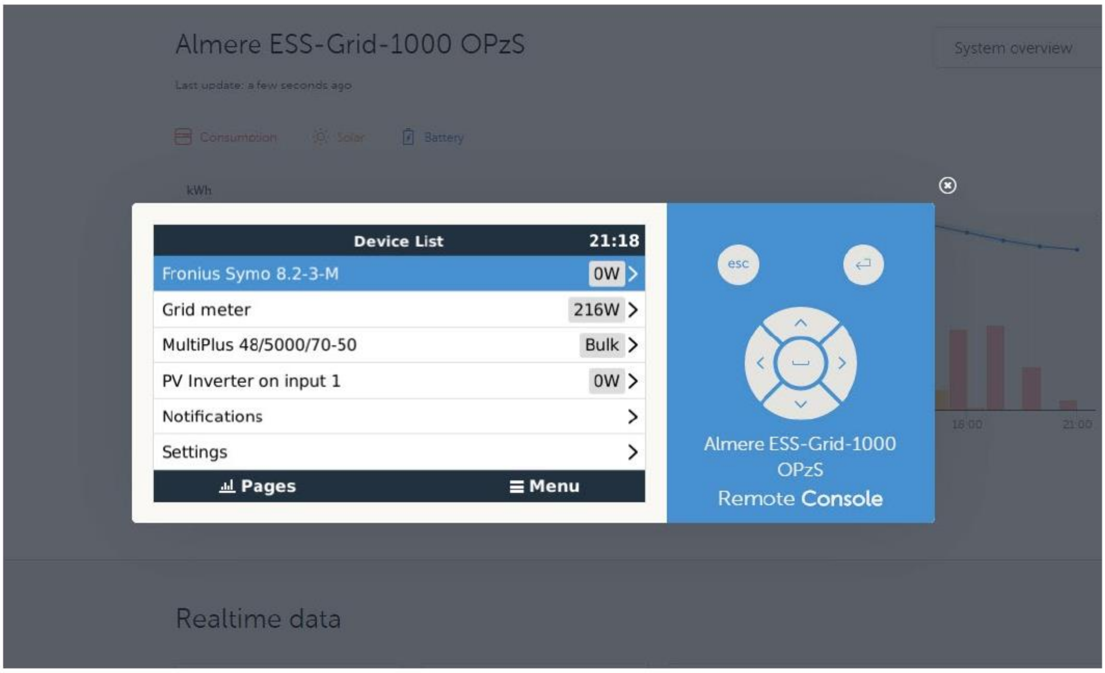


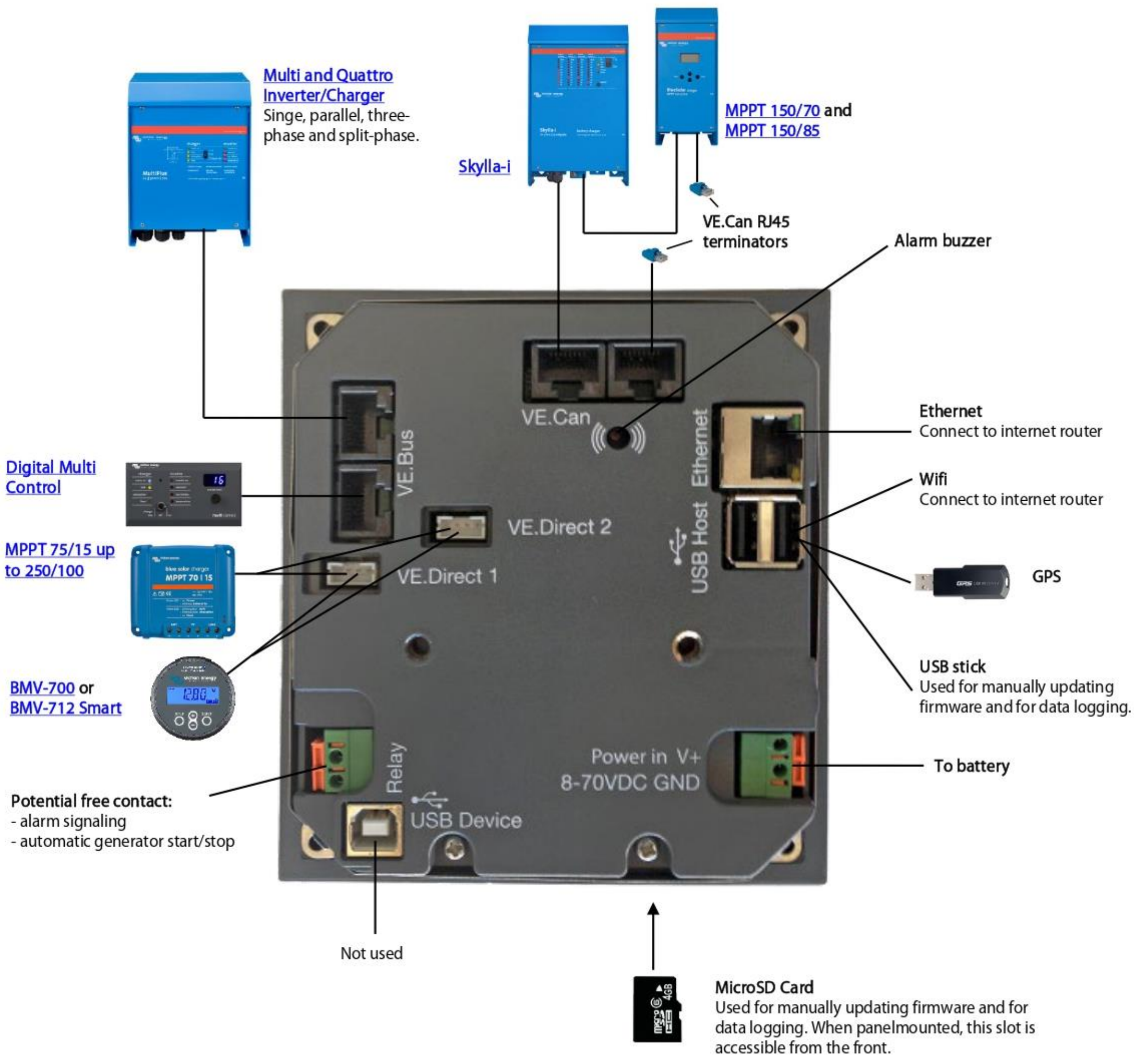
Tiles overview

VRM Portal - Dashboard



VRM Portal – Remote Console




Multi and Quattro Inverter/Charger
Singe, parallel, three-phase and split-phase.
Skylla-i
MPPT 150/70 and MPPT 150/85
VE.Can RJ45 terminators
Alarm buzzer
VE.Can
VE.Bus
Ethernet
Connect to internet router
Wifi
Connect to internet router
USB Host
GPS
Digital Multi Control
VE.Direct 2
MPPT 75/15 up to 250/100
VE.Direct 1
BMV-700 or BMV-712 Smart
USB stick
Used for manually updating firmware and for data logging.
Relay
Power in V+
8-70VDC GND
To battery
Potential free contact:
- alarm signaling
- automatic generator start/stop
USB Device
Not used
MicroSD Card
Used for manually updating firmware and for data logging. When panelmounted, this slot is accessible from the front.

Annex F

ACE6000

Commercial Electricity Meter Portfolio

ACE6000 four-quadrant load profiling meters support the new needs arising from deregulation and competition in the electricity market as well as classic metering.

Smart

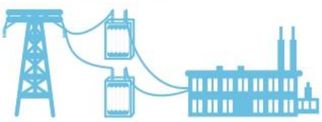
Compliant with IEC standards, these meters include large innovative capabilities.

They allow multiple recording of load profiles along with local and remote communication.

Flexible

Designed for direct or transformer connection, ACE6000 meters employ a scalable architecture that makes them equally suitable for use with existing and new electricity distribution networks.

Wide Range of Applications



Thanks to an auto-ranging power supply and wide measuring range, a single meter type can be used across a variety of applications – from large commercial installations to industrial metering.

Accuracy and linearity ensure high quality billing data (including Load Profiles).

Instantaneous values for a variety of quantities serve as a base for network monitoring.

PSTN, GSM, GPRS and IP communications are supported thanks to DLMS-Cosem Protocol.

ADDING VALUE

Through the application of the latest-generation metrological and communications technologies, ACE6000 meters bring significant benefits to utilities and end-users alike, adding value to every aspect of the metering process.

Utility Benefits

» Reduced Inventory Cost
Thanks to a wide measuring range and auto-ranging power supply, industrial and commercial users need only one type of meter for many types of installations.

» Reduced Data Collection Cost
Read cycles are kept to a minimum by internal storage of all billing data, and powerful communications capabilities permit low-cost remote meter reading. Conformance with the latest IEC DLMS-Cosem communications standards ensures that the meters can be integrated easily into standard data collection systems as well as future GPRS or IP based systems.

» Reduced Non-Technical Losses
Multiple safety features guard against technical problems being introduced by human intervention.

» Withstand Adverse Environments
Our meters are designed and tested to cope with severe environmental conditions, such as electromagnetic disturbances and network condition variations.

End-User Benefits

» Excess Consumption Feature
ACE6000 meters can monitor consumption against configurable thresholds and can activate contacts if consumption exceeds limits.

» Instantaneous values such as Power Factor, Demand, Volts and Amps are made available for the end-user to help monitor personal consumption.

KEY FEATURES

Multi-Energy

Internal measurement of active and reactive power in each direction.

Load Profiles

Up to 16 channels for various base quantities into two independent profiles

Multi-Rate

- Multi-rate billing for energy and demand
- 10 basic quantities can be submitted to billing
- 32 energy-rate and 24 demand-rate registers are available
- Rate switching performed by internal clock

Smart metering features:

- Remote/Local connect/disconnect meter installation through external contactor
- Meter communication lock after wrong passwords sessions
- EN50160 compliancy
- Deliver modem information on demand

Communications

- Two communication channels
- Local- and remote-reading ports
- External telephone modem can be supplied from the meter, (PSTN, GSM)
- DLMS-Cosem compliance opens to GPRS and IP networks

Software

Itron offers a complete range of associated software:

- ACE Pilot software for reading and programming
- Compatibility with already deployed AMR systems

ACE6000 Meter series

- Basic version without outputs with 1 serial port
- Flexible version with 4 outputs and 1 serial port
- Serial port can either be RS232 or RS485

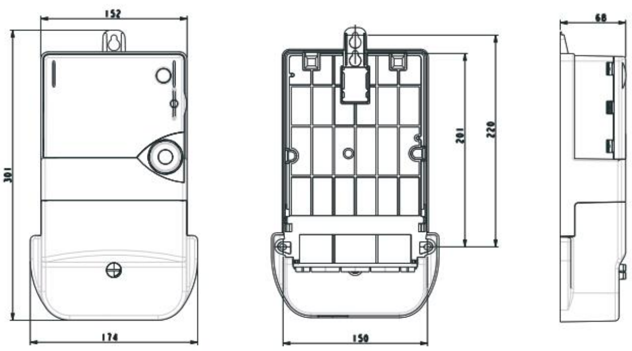
Technical Specifications

Ratings	Voltage: Direct Current: Ct/Connection:	3*57.7/100V up to 3*277/480V auto ranging Ib 5A, Imax 100A Ib 1A, Imax 10A
Network Types	Direct Connection: C/t, v/t connection:	4-wire meter, fully operational in 3-wire connection without neutral 3- and 4-wire configurable connections (for asymetrical VDE or symetrical USE connections)
Accuracy	Direct Connected: Transformer Connected: Reactive energy:	Active energy MID: Class B Active energy Class 0.5S & MID: Class B Class 2 or Class C
Frequency	50 / 60 Hz	
Real Time Clock	Back up with external removable battery and internal super capacitor Compliant with IEC 62054-21	
Operating Temperature Range	-40°C to +70°C (specific variant for high temperature operating conditions)	
Standards	Full compliance with MID standard EN50470-1 and EN50470-3 and CE marking standards (mechanical, climatic, electrical, electromechanical, metrological)	
Communications	IR-port (IEC 62056/21 and IEC 62056/42-46-53-61-62) RS232C or RS485 DLMS-Cosem, Protocol (IEC 62056/42-46-53-61-62)	

Accessories

Communications	External telephone modem Cabling for external communications devices IR-reading device for connection to PC Itron Sparklet modem is easily inserted under the ACE6000 terminal cover.
Configuration/ Calibration	ACE Pilot Utility Software for configuration and reading
Documentation	Test certificate User guide Installation Manual

Dimensions



Itron

Itron is the leading provider of energy and water resource management solutions for nearly 8,000 utilities around the world. We offer end-to-end solutions that include electricity, gas, water and heat measurement and control technology; communications systems; software; and professional services. With nearly 10,000 employees doing business in more than 130 countries, Itron empowers utilities to responsibly and efficiently manage energy and water. To realize your smarter energy and water future, start here: **www.itron.com**

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